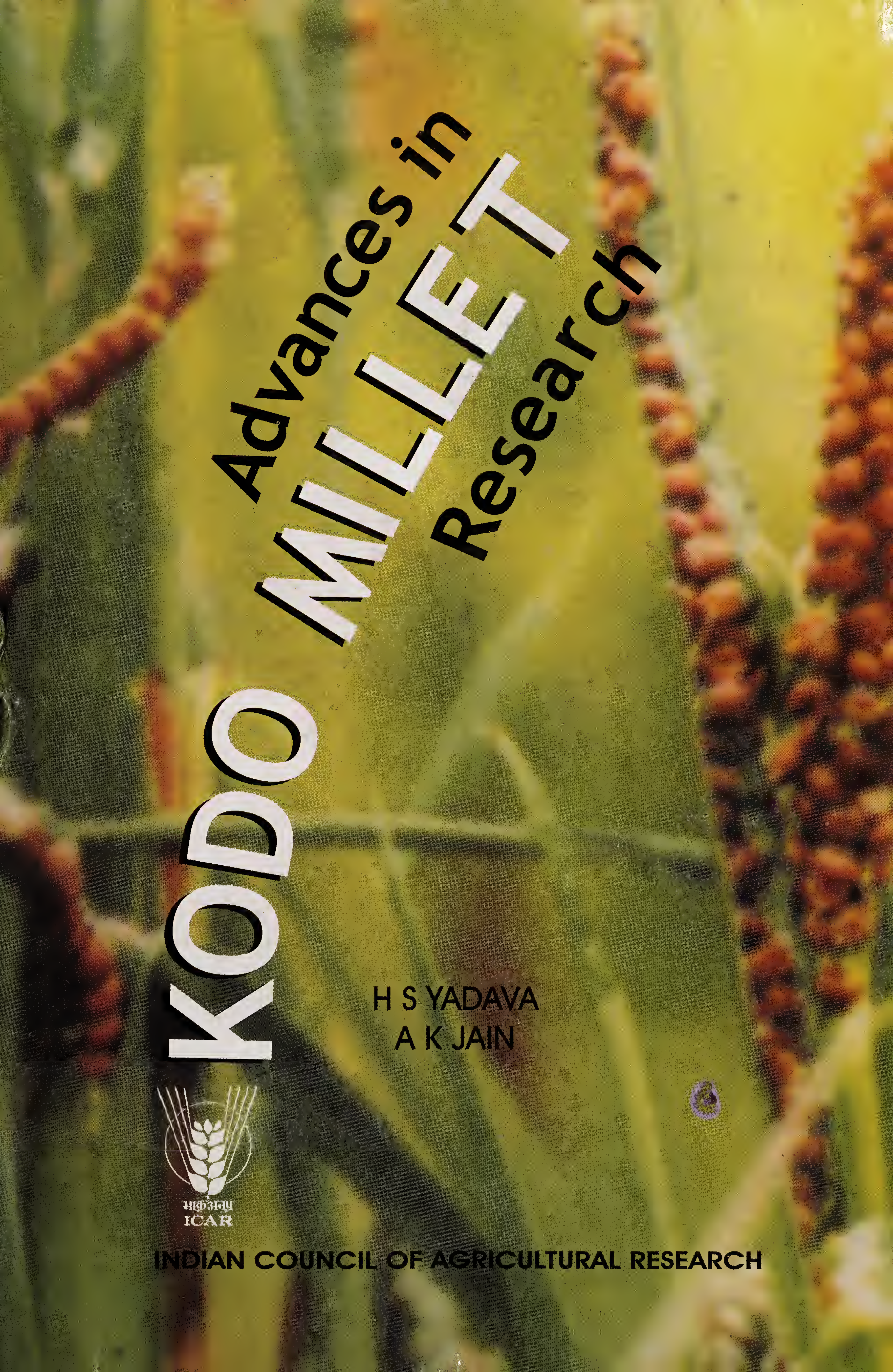

Advances in KODO MILLET Research

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भाकृअनुप
ICAR

INDIAN COUNCIL OF AGRICULTURAL RESEARCH

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Foreword

Small millets are important foodgrains in the diets of a large section of population in India. The use of these crops is confined to certain geographic regions and is common in the lower socio-economic group of population. No doubt, most important utilization of these crops is for food but also their leaves and culms are nutritious fodder for cattles. In future, profitability and sustainability of crop production systems are going to be the decisive factors. This is more so in small millets, since they will be facing severe competition from other cash crops. It should be possible to generate more income from small millets based production systems through proper blend of crops, systems and technologies.

Kodo millet is indigenous to Indian sub-continent and ranks first among small millets excluding finger millet. It contributes about 37% and 31% to total area and production of small millets in the country. Madhya Pradesh shares the major area (71.7%), followed by Uttar Pradesh, Tamil Nadu, Gujarat, Maharashtra and Karnataka. Kodo millet is a self-pollinated crop and is nutritionally comparable or even superior to major cereals and other millets. It is grown predominantly as sole crop as well as mixed with redgram, greengram, blackgram, sesame and sorghum. The crop also responds favourably to the application of FYM and biofertilizers, which minimizes the cost of production. The crop is generally less affected by biotic and abiotic stresses. The grains of kodo millet can be stored for several years without damage from stored grain pest. Thus crop is known as famine grain. Kodo millet is used as traditional food, fast food fermented brew, fodder for cattle, construction of earthern houses and raw material for many industrial products. The crop has high therapeutic value also.

The present book contains up-to-date information about crop with respect to its botany, physiology, improvement, production, protection, nutritive value and its utilization, which is indeed a necessity. In this context, the efforts made by the authors are noteworthy and I compliment their efforts.

It is hoped that this book will be useful as a reference book to the scientists, students and field personnel working on the crops.

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Preface

Kodo millet (*Paspalum scrobiculatum* L.) is one of the small grain cereals with cultivation history of more than 3,000 years in Indian sub-continent. Wider adaptability, easy cultivation, ability to tolerate the biotic and abiotic stresses have made this crop as a major component of dry farming ecosystem. The crop is not as important in terms of world food production but it is essential as a food in their agro-ecosystem.

In India, the cultivation of kodo millet is quite widespread. The crop is grown with substantial area in Madhya Pradesh, Chhattisgarh, Maharashtra, Uttar Pradesh, Gujarat and Tamil Nadu. Inspite of declining area, during last four decades, the production has been more or less maintained by increased productivity.

Recognizing the need of kodo millet in sustainable agriculture, ICAR initiated All-India Co-ordinated Small Millets Improvement Project in 1986 in collaboration with State Agricultural Universities. This multi-disciplinary approach has generated new technologies for boosting the productivity of kodo millet substantially. However, the impact of these technologies is marginal with wide research and extension gaps. The new production technologies have not reached to the growers in a meaningful way. Infact, most of the research findings have remained scattered and probably confined to scientific reports. This compilation brings together, perhaps for the first time, all the relevant research in kodo millet. It is hoped that the compiled information will be useful not only to the growers, but the research workers and planners who are interested in raising the sustainability, stability and productivity of kodo millet.

Thanks are due to Dr A Seetharam, the former Project Co-ordinator (Small millets), UAS, GKVK, Bangalore for necessary encouragement to compile this work. We wish to record the sincere gratitude to Dr R C Gautam, Dean and Joint Director, IARI, New Delhi for going through the manuscript and making valuable suggestions for the improvement.

The authors are indebted to Dr Panjab Singh, Dr G B Singh, the former and Dr D P Singh, the present Hon'ble Vice-Chancellors, Jawaharlal Nehru Krishi Vishwa Vidyalaya (JNKVV), Jabalpur for their motivation, encouragement and constant support.

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Contents

CHAPTER 1

Introduction

Small millets constitute a group of small seeded cereal species. The wide adoptions of these crops have made their cultivation as component of dry land agriculture in tropics and subtropics. These crops provide assured and reasonable harvest from the lands where the major cereals failed to give sustainable yield. Small millets are thus not important in terms of food production but they are essential as staple food in their respective ecosystem.

The eight small millet crops are important in global agriculture. These are grown in fairly large area of South Asia, China, USSR and Africa. They are also found in limited scale in the areas of United States and Europe. The diversified agricultural assets in terms of soil, rainfall and climate favours the cultivation of only six small millets in India. These are finger millet (*Eleusine coracana* L. Gaertn.), kodo millet (*Paspalum scrobiculatum* L.), little millet (*Panicum sumatrense* Roth ex Roem. & Schult.), foxtail millet (*Setaria italica* L. Beauv.), barnyard millet (*Echinochloa colonum* Link) and proso millet (*Panicum miliaceum* L.). Rest of the two small millets namely, fonio millet [*Digitaria exilis* (Kipp.) Stapf] and telf (*Eragrostis tef* (Zucc.) Trotter) are of local importance in Africa.

IMPORTANCE OF KODO MILLET IN INDIAN AGRICULTURE

Kodo millet is one of the hardiest crop among the small millets. The crop possess a number of valuable characteristics such as more herbage, branched ear, large number of seeds per ear, high fertility and unique storage ability. Kodo millet has considerable production potential in marginal, low fertility soils and chronic moisture deficient areas of the country. These characteristics of kodo millet are mainly responsible for its existence and survival in many parts of the country inspite of recent modernization in agricultural system. The salient features of the crop pertaining to its importance in Indian agriculture are briefly mentioned below:

Regional Food Security

Kodo millet is a balanced and staple food of tribal and economically poor section of the population. It provide low priced proteins, minerals

and vitamins in form of sustainable food. Food is produced locally from such pieces of land which are rather unsuitable for cultivation of major cereals. The grains of kodo millet possess excellent storage properties and can be stored for several years without fear of damage from store grain pest even under ordinary storage conditions. It is the reason that crop is locally known as famine grain. It should be thus feasible to build up the stock as famine reserve through large scale procurement in the years of excess production. The building of such stock locally at farm level makes significant contribution in achieving the regional food security.

Sustaining production in dryland

The wide adaptation, poor resource based production, early maturity and assured harvest of kodo millet are the features of kodo millet production. It is a drought resistant crop, demands little cash inputs in their production. The crop has been ecologically sound and environment friendly because of negligible use of pesticide in its production. Notwithstanding the low contribution to total food grain production, kodo millet offers enormous advantage in the area of their ecosystem. The vast untapped potential exists in technology presently available in the crop. The crop yield can be increased as high as 38% by varietal replacement (Seetharam, 1998). The immediate need is to encash this high yielding variety (HYV) technology through massive seed production and its distribution. The vigorous extension, which is almost presently absent can bridge up the gap in existing yield level of this crop.

Contingency planning

Abnormal monsoon is becoming a frequent feature in recent years. Under situations of delayed monsoon, kodo millet is an excellent crop for contingency planning because of their photo-insensitivity, drought tolerance ability and quick growing habit. Although the proso millet and little millet are the first crop to mature in rainy season but kodo millet varieties of nearly similar duration are available for contingency planning in abnormal sowing seasons.

Feed and fodder

Mono cropping is prevalent in most of the kodo millet growing areas of the country. It results in long gap of several months between harvest of one crop and sowing of subsequent crop obviously, there is very high seasonal dependence on dry fodder for animal feeding during dry months. The stover of kodo millet is used as feed for cattle in these situations. Kodo plant is also used as a green fodder in early stage of the crop.

The increasing incomes of the Indian population keep a pressure on meat, milk and other animal products. There is an increased shortage of feed in the country. The feed requirement is met from best food grains in general and made especially from coarse grains. The demand for animal and poultry feed placed a demand in turn on coarse cereals. Kodo millet being rich source of proteinaceous meals, minerals and vitamins can furnish several essential substance required for body growth, maintenance, production and reproduction of birds and animals.

Breakfast and food products

A lot of breakfast food and snacks are available in the Indian market. The demand is likely to increase because of increasing function of the trendy and westernize urban population of working women. The statistics are however, not available on how much quantities of small millets are used in these industries but there is ample possibilities for utilization of kodo millet grains in the preparation of breakfast products, health foods, bakery products and snacks either alone or in combination with grains of other cereals.

Raw material for industry

Like other coarse cereals, kodo millet has tremendous potential to be used as raw material in industry for preparations of readymade food, bird feed, extraction of starch, adjust in braving malt and milk beverages. The starch industry in India had bright future because it is the source of material to dextrins, modified starches, oxidized starches, gelatinize starches and starch derivatives.

Export possibilities

The grains of kodo millet can be exported for use as bird feed and health care food to the countries of Japan, Russia, Africa and some European countries.

Traditional crop heritage

Modernization in agriculture and spread of HYVs in major crops have resulted in loss of some valuable gene pools. The complete replacement of kodo millet by remunerative crops is practically very difficult even in 21st century, because kodo millet gives assured harvest from such piece of land where other crops fail to survive. Seeing the realization of its tolerance ability to chronic stresses it becomes important to maintain and conserve this crop along with traditional food culture and religious celebration. The crop may attain an important position as food grain and fodder in future because of fast changes in ambient atmosphere.

DISTRIBUTION IN INDIA AND ABROAD

Kodo millet is widely distributed in damp habitat across the old world tropics. The crop is harvested as a cereal in West Africa and in India. Kodo millet is also grown in hot arid regions of Asia, New Zealand and USA as a pasture crop. In India, the crop is cultivated in Madhya Pradesh, Chattisgarh,Uttar Pradesh, Tamil Nadu, Gujarat, Maharashtra, Andhra Pradesh and Karnataka. The major Kodo millet growing districts are Mandla, Chhindwara, Shahdol, Sidhi, Seoni, Betul, Rewa, Jabalpur and Satna in Madhya Pradesh; Rajnandgaon, Durg, Raipur, Bilaspur, Sarguja and Rajgarh in Chhatisgarh; Mirjapur, Basti, Gorakhpur and Deoria in Uttar Pradesh; Trichy, South Arcot, Salem, Pudukkattai, Kamaragar, Madurai and Dindigul-Anna in Tamilnadu; Panchmahals, Kheds, Baroda, Surat and Bharuch in Gujarat; Ratnagiri Dhule and Sindhudurg in Maharashtra; Tumkur, Chitradurga and Gulbarga in Karnataka; and Prakasam, Mehboobnagar and Kurnool in Andhra Pradesh (Singh, 1994b).

AREA, PRODUCTION AND PRODUCTIVITY

The statistics pertaining to area, production and productivity of small millets is mostly reported for the whole crops with no distinction made for individual crop. However, the Directorate of Millets Development, Jaipur had tried to generate this statistics for individual small millet crops based on available record and personal communications (Bondale, 1994 and Singh, 1994b). Accordingly, kodo millet is grown in an area of about 907,800 ha with annual production of about 310,710 tonnes. Among the small millets excluding finger millet, kodo millet shares 36.61 and 31.52% of total area and production of the country (Fig. 1). The national average

Table1. Area, production and productivity of kodo millet in different states of the country

State	Area ('000 ha)	Rank	Production ('000 tonnes)	Rank	Productivity (kg/ha)	Rank
Andhra Pradesh	5.0	VII	1.08	VII	215	VII
Gujarat	42.0	IV	15.58	IV	371	IV
Karnataka	12.0	VI	2.71	VI	226	VI
Madhya Pradesh	651.0	I	152.33	I	234	V
Maharashtra	26.0	V	11.60	V	446	III
Tamil Nadu	70.6	III	77.72	II	538	I
Uttar Pradesh	101.4	II	49.69	III	490	II
India	907.8		310.71			

Source: Bondale (1994) and Singh (1994b)

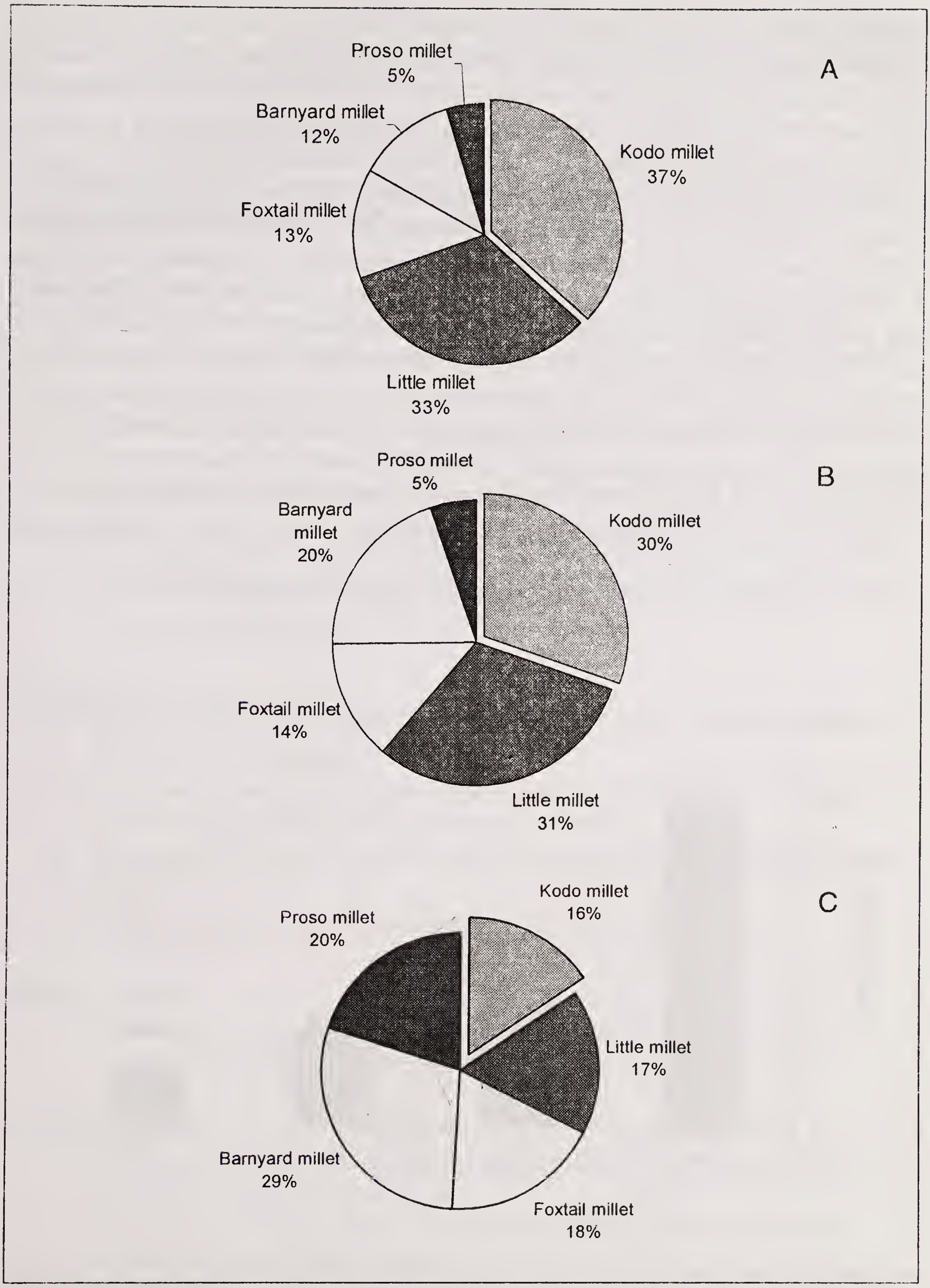

Fig. 1. Share of kodo millet in area (*A*), production (*B*) and productivity (*C*) among small millets in India.

Source: Bondale (1994) and Singh (1994b)

productivity of kodo millet is around 342 kg/ha. Kodo millet is predominantly grown in Madhya Pradesh, which shares an area of nearly 71.71% to its total area in the country. Uttar Pradesh ranks second followed by Tamil Nadu, Gujarat, Maharashtra, Karnataka and Andhra Pradesh. The productivity is highest in Tamil Nadu followed by Uttar Pradesh whereas it is lowest in Andhra Pradesh followed by Karnataka and Madhya Pradesh (Table 1). The trend of estimated area and yield level of Kodo millet in last 35 years in Madhya Pradesh showed a decrease in area from 1 million hectares (1975–76) to 0.65 million hectares (1998–99). However, the productivity showed an increasing trend from 210.9 kg/ha (average of 1971 to 1985) to 303 kg/ha during 1998 (Department of Agriculture, Madhya Pradesh, 1998). The enhancement in productivity of kodo millet in recent past is due to adoption and impact of developed technologies on this crop. However, considerable yield gap exists in the yield level of kodo millet recorded during 1993-94 in experimental fields, demonstrations on farmers field and average productivity of the country (Fig. 2). This gap

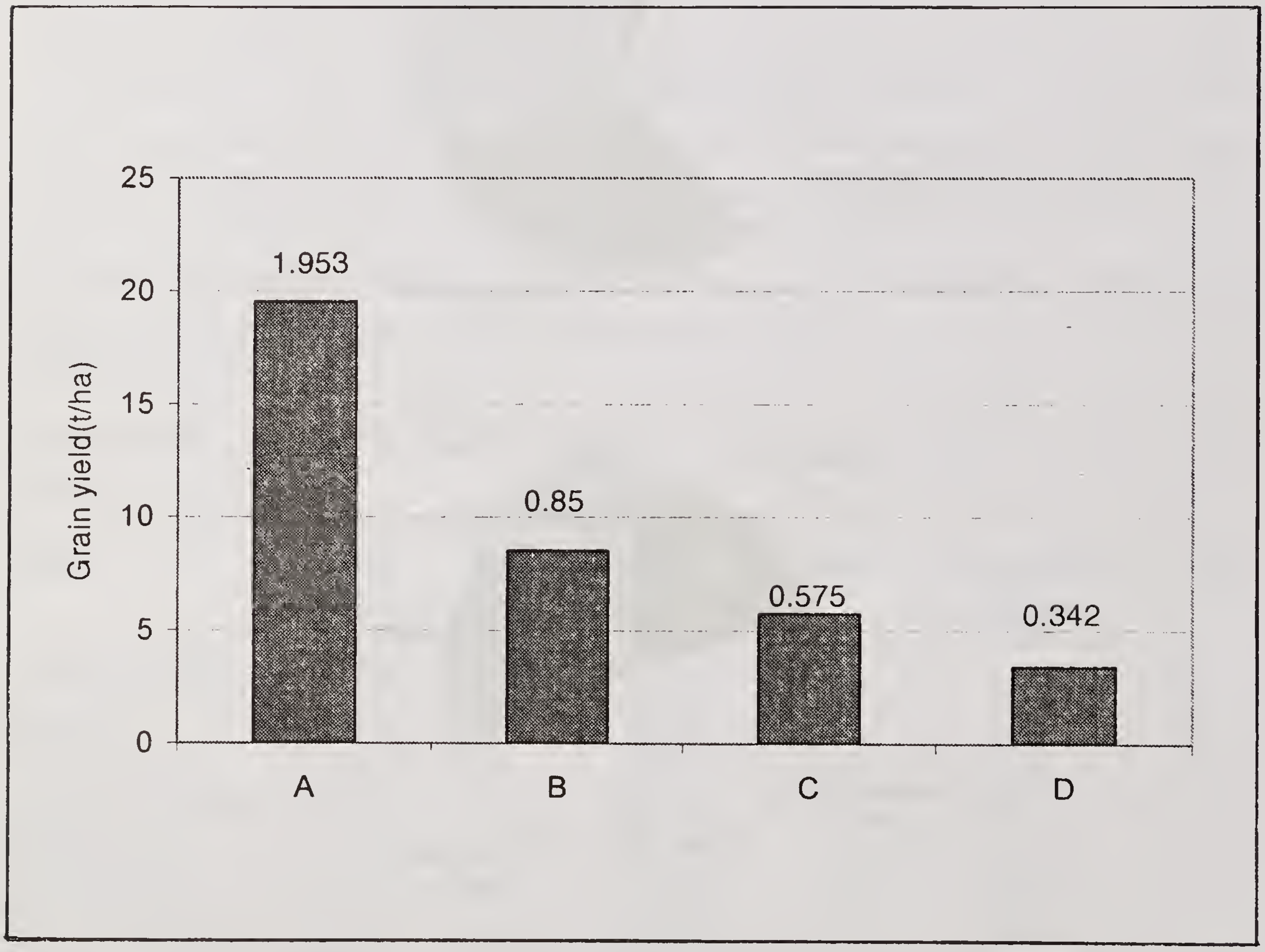

Fig. 2. Bridgeable gaps in productivity of kodo millet in India. *A* Seed yield at research station; *B*, seed yield in improved practices at farmers' field; *C*, seed yield in local practices at farmers' field; and *D*, national average

Source: UAS, Bangalore (1994)

can be bridged up through massive extension efforts for popularization of high yielding varieties and minimum nutrient uses in form of fertilizers or manures.

FACTORS RESPONSIBLE FOR LOW YIELD

The environmental, agronomic, biotic and social factors responsible for low yield level of kodo millet are given below.

Environmental factors

1. Kodo millet is generally grown in marginal and shallow soils where native fertility and moisture retention capacity of the soils are very low.
2. Being a rainfed crop, recurrent drought is a common feature due to erratic behaviour of rains.
3. The severe soil erosion constantly reduces the soil fertility in hilly areas.
4. The cultivation of kodo millet is restricted mostly in hills, where altitude, longitude, rainfall, aspects of hill and soil characteristics varies considerably.

Agronomic factors

1. Kodo millet is cultivated in sustenance level of farming with low level of management.
2. Generally low yielding land races are in cultivation and the rate of their replacement with HYVs is very slow.
3. Practically no cash inputs in form of fertilizers are applied to the crop.
4. Weed competition is always there in kodo millet crop.

Biotic factors

1. Head smut and shoot fly reduces the yield to certain extent in susceptible genotypes of kodo millet.

Social factors

1. Being a crop of tribal and hill farmers, there is always resource constraint with the growers.
2. Rigidity of tribal farmers to their ancestral package and slow extension due to illiteracy.
3. Dearth of remunerative market for the produce of kodo millet.
4. Lack of appreciation of nutritive value of the crop.

NEED FOR BOOSTING THE PRODUCTION

The contribution of kodo millet to total food grain production is although very low but the crop provide staple food in agroecosystem. The reduction in production definitely results from an imbalance in total cereal production and majority of the weaker section of the population suffers from hunger. Realising the need and role of this crop, the emphasis should be made to boost their production up to 0.6 million tonnes by 2020 AD for fulfilling the demands of increasing population (Yadava, 1997b).

CHAPTER 2

Origin and Botany

ORIGIN OF THE CROP AND DOMESTICATION

Kodo millet is a native of India and is in cultivation since time immemorial. It is mentioned in *BRIHAD SANHITA*

ज्येप्ठे जातिकुल धनश्रेणी श्रेष्ठा नूपाः सधर्मझा
पीज्यन्ते धान्यानि च हित्वा कड्गं समीजातिम

It indicates that when Jupiter is leader in the year of Jyestha, majority of the population will enter in trouble due to famine and only the grain like kodo (*kodra*) and *kutki* (*Samai*) will survive.

The drought stress tolerance ability of kodo millet is known since ancient past. The crop was domesticated in southern Rajasthan and Maharashtra some 3,000 years ago (Kajale,1977). The greater diversity in *Paspalum* species is found in Indian (Hindustan) centre, which is suppose to be centre of origin of this crop. Being indigenous to India, the crop was distributed throughout the tropical region of the world.

Taxonomic classification

Family	:	Poaceae (Gramineae)
Sub-family	:	Panicoideae
Tribe	:	Paniceae
Genus	:	*Paspalum*

Species and races

The genus includes about 250 species among them *Paspalum scrobiculatum* L., *P. notatum* Fluegge, *P. conjugatum* Bergius, *P. compactum* Roth and *P. dilatatum* Poir. are in cultivation, as grain or fodder crop. The wild progenitor of *Paspalum* species is *P. sanguinale* Lamk. As early as 1772-86, the four species of *Paspalum*, namely *P. compactum*, *P. conjugatum*, *P. orbiculare* Forster. and *P. scrobiculatum*, were reported from Hasan district of Karnataka (Saldanha and Nicolson, 1978).

Three races of *P. scrobiculatum* have been recognised based on the arrangement of spikelets on the rachis. They are *regularis*, *irregularis* and *variabilis* (Prasad Rao *et al.*, 1993). The kodo millet is characterized by

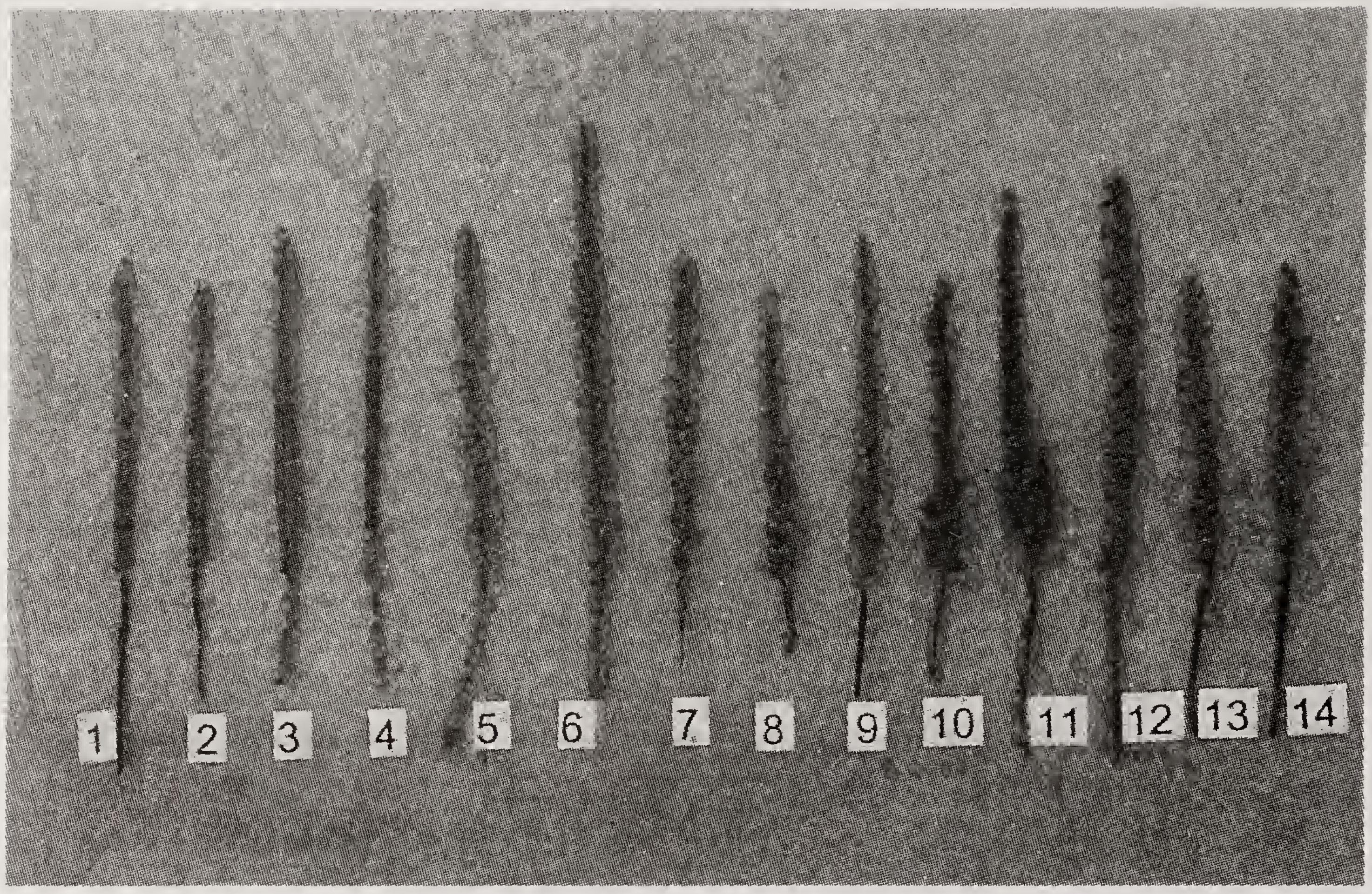

Fig. 3. Variation in spikelets arrangement on ranchis in kodo millet
Source: All-India Co-ordinated Research Project on Small Millets, Rewa (Madhya Pradesh)

racemes with the spikelets arranged in two rows on one side of flattened rachis in the race *regularis.* The plant with spikelets arranged along the rachis in 2 to 4 irregular rows forms the race *irregularis.* In some of the kodo plants, the lower part of the each raceme possessed irregularly arranged spikelets, while upper part has two regular rows of spikelet arrangement on the rachis. These plants are known as *variabilis* race (Fig. 3).

Chromosome number

Paspalum scrobiculatum is predominantly a self pollinated plant having chromosome number 2n=40. The chromosome number varies from 2n=20 to 2n=60 in genus *Paspalum* (Bashaw and Forbes, 1958). The chromosome number in knot grass (*Paspalum gigantium*) is reported to be 2n=120 (Chandrasekharan and Parthasarathy, 1975). The chromosome numbers of some *Paspalum* species are given in Table 2.

Indian colloquial names of kodo millet

Kodo adhan (Bengali); *kodo, kodai* (Bhojpuri); *harika, kodra, kodri, kodroakora, pakod, pakodi* (Marathi); *kodra, kodro, menya* (Gujarati); *koda, kodaka, kodava, kodo* (Hindi); *harika* (Kannad); *varagu* (Tamil); *pacodd, pacoll* (Konkani).

Table 2. Chromosome numbers of *Paspalum* species

Species	Chromosome number (2n)	Common name
Paspalum commersonii	40	-
P. conjugatum	40	Sour grass
P. dilatatum	40,50	Dallis grass
P. distichum	40, 48, 60	Water couch grass
P. gigantium	120	Knot grass
P. lanceolatum	40	-
P. longifolium	40	-
P. muchlenbergii	18, 20, 22	-
P. notatum	20, 40	Bahia grass
P. quandreferium	20, 30, 60	-
P. scrobiculatum	40	Kodo millet
P. setaceum	40	-
P. virgatum	40, 80	-

Source: Chandrasekharan and Parthasarathy (1975)

Botanical description of *Paspalum scrobiculatum*

Habit : Annual Herb

Root : Adventitious root arises from lower nodes with numerous thin roots. Branched roots spread laterally and profusely, remain functional throughout the life.

Stem : Erect rarely ascending with 60–90 cm height, tufted on a very short rhizome. Glabrous stem with swollen nodes and fully sheathed internodes. Nodal bands become purple at later stage. First node is hairy and the other nodes are glabrous with solid internodes. The length of internodes increases gradually from bottom to top in any tillers. The number of tillers varies from 5 to 18 according to genotypes.

Leaf : Simple, alternate, bifarious, erect or suberect, finely acuminate, glabrous or sometimes soft hairy. Sheaths long, compressed, loose, the mouth hairy with very short membranous ligule.

Inflorescence : Usually a spike or spike like racemes. Each spikelet consists of 1 or 2 flowers and bears at the base bracts or glumes, one placed a little above and opposite the other. These two are empty while a third one called lemma is flowering i.e. it enclosed a flower in its axil. Opposite the flowering glume or Lemma,

there is somewhat smaller, two nerved glumes called Palea. Spikes 2–6, sessile usually distant and spreading, rachis herbaceous, broad with ciliate margins. Spikelets usually 2 ranked, 2–3 mm diameter, sessile or shortly pedicilate, broadly elliptic or suborbicular imbricate.

Androecium : Stamens 3, filamentous, anthers 3, 2 locules, open by longitudinal sutures, versatile and pendulous.

Gynoecium : Monocarpellary, ovary superior, one cell with one ovule, stigma 2, feathery, style distinct.

Grain : Utricle type in which pericarp is like a sac usually attached to endosperm at only one point. Grains are rotundate-elliptic, convex in front, flat on back of palea, scutellum up to half the length of the grain.

Floral formula : P Lodicules (2) A_3 G_1

FLOWERING BEHAVIOUR

Flowers of kodo millet are cleistogamous in nature and thus remained closed. Protogynous flowers occurs rarely in few genotypes. Youngman and Roy (1923) were the first who noted the opening of the flowers in kodo millet. They observed opening of the flowers between 7.30 to 8.00 AM in Nagpur conditions. Only 5% flowers open and remaining being cleistogamous. The detailed observations on the anthesis were carried out at Coimbatore by Ayyangar and Panduranga Rao (1934). According to them the glumes begin to open at 2.30 AM. The anthers become visible through opening at 2.40 AM, emerge at 3.15 AM and comes completely out at 3.30 AM. Anther dehisce at 3.35 AM and glumes closed completely at 3.45 AM. They further observed that the anthers crowd at the orfice, non-emergent and undehisced, but emerged in rare cases. The dehiscence of anther occurred by a slit at one end and speed up gradually. Mostly the dehiscence of anther begins from the middle and proceed to both ends. The feathery stigma dry up in the evening. The anthers remains fresh and do not wither till next morning. The lodicules are fleshy and do not shrink immediately after the anthesis of flowers. They remain fleshy for 6 to 8 hour after opening the glume and then dried up. The grains mature in 30-40 days after flowering and remain tightly enclosed by the hardened fourth glume and its palea and have various shades of brown colour.

Verma (1989) found the best time of anthesis between 5.45 and 7.30 AM. In this period a single floret of panicle open for 20 to 30 minutes. The stigma comes first during anthesis of flowers and anthers arises just after the emergence of stigma. Yadava (1997a) studied the flowering behavior

of kodo millet with the help of a protogynous induced mutant (KM 32). In this mutant the opening of flowers starts automatically on day 3 after complete panicle emergence. The flowering starts from middle of the panicle and proceed to both sides. The flowering in a panicle takes nearly a week to complete. The best time of blooming was from 6 to 11.30 AM. The dehiscence of anthers take place after change in their colour from whitish to light yellow.

APOMIXIS

Burton (1948) recorded the apomixis in *Paspalum notatum* while Hayman (1956) reported apomixis in *P. dilatatum*. The apomixis particularly gametophytic apomixis results from either failure of meiosis or failure of fertilization or parthenogenetic development of egg cell into embryo. These events may be independent and controlled by separate genic system. Thus the breeding and crossing procedure involving apomixis in different species would vary depending upon gene action for apomixis, levels of apomixis and ploidy levels of the parents. Talioferro and Bashaw (1966) proposed an outline for breeding obligate apomictic buffel grass by using either selfing or crossing technique followed by selection and evaluation. Burton and Forbes (1960) doubled the chromosome number of sexually diploid Bahia grass (*P. notatum*) to make the crosses compatible with obligate apomictic tetraploid of this species. It resulted in release of genetic variability and isolation of some promising lines of Bahia grass. Thus the facultative apomixis can be successfully manipulated to develop the improved genotypes. Such possibilities deserve priority in *P. scrobiculatum* for release of transgressive variation.

Emasculation techniques

Emasculation is the removal of anthers or killing of the pollen grains without affecting the gynoecium. The small and delicate spikelets combined with brittleness of the rachis makes the emasculation tedious in kodo millet. The cleistogamous nature of flowering also adversely affect the success in emasculation. However, hand emasculation, hot water emasculation and suction method of emasculation are in practice to certain extent within their limitations in protogynous genotypes.

Hand emasculation

Hand emasculation is performed before the anthers are matured and stigma has become receptive to minimize the incidental self pollination. In this process the premature anthers are removed with the help of forceps. Ayyangar and Warian Achuta (1934) was first to describe a method for

hand emasculation in finger millet, which is being used in kodo millet also. According to this method, the spikelet is prepared on the previous evening by removing all the other flowers except those which are likely to open in next morning. The anthers are then removed by opening the glumes with a pair of fine forceps. The emasculated flowers are to prevent cross pollination. The emasculation technique developed by Verma (1989) involve the stimulation of flowers by irrigating the plant one night prior to their anthesis. It resulted in better opening of florets of a panicle in kodo millet. Then anthers are removed easily with the help of fine forceps. One major limitation in this method was opening of a single floret which mostly depends on ambient temperature and humidity. Yadava (1997a) has standardized the technique of hand emasculation with the help of a protogynous mutant. In this mutant the opening of florets commenced automatically on third day after complete panicle emergence. Flowering progress from middle to both sides of the panicle. During the flowering, a single floret remain open for 20-30 minutes. In the process of flower opening, the white feathery stigma produced first and whitish anthers comes after 10 to 15 minutes. The anthers dehisce after the change in their colour from whitish to light yellowish. The whitish anthers could be thus easily removed with the help of forceps. This technique is being used for making the crosses in kodo millet.

Hot water emasculation

In this technique, the pollen grains are killed by hot water treatment. In the case of hot water emasculation, the temperature of water and duration of treatment varies in different crops. In small millets, the water temperature of 48–49°C for 6 minutes has been found effective in killing the viable pollen grains (UAS, Bangalore, 1995). The hot water treatment is given either before dehiscence of anther or prior to opening of florets with the help of thermos flask and whole spike is submerged in the water.

Suction method of emasculation

This method is useful in species with small flowers. Emasculation is done in the morning just before or immediately after the flowers open. A thin rubber or glass tube attached to a suction hose is used to suck the anthers from the flowers. The tube is also passed over the stigma to suck the pollen grains from it's surface. This method may be used for quick and successful emasculation in kodo millet.

CROP PHYSIOLOGY

Paspalum scrobiculatum L. is a C_4 plant, responds favourably to warm

conditions. The virtual absence of photo-respiration with certain other biochemical specialization gives them a higher optimum temperature for photosynthesis. This characteristic promote ecological dominance of kodo millet in the tropics and subtropics where environmental conditions are highly conductive to rapid growth of C_4 plants. Hall (1976) reported that C_4 plants have faster rate of specific assimilate mass transfer through their leaf blade than C_3 grasses. *Paspalum dilatatum* Poir. have specific assimilate mass transfer rate of 12.7 g dry weight/cm^2. A combination of low temperature (10°C) but high light intensity (160 W/m^2) imposes climatic stresses in *P. dilatatum*. The photosynthetic response is reminiscent to chilling injury. Yellowing tips on leaves of *Paspalum* are in fact a visual indication of their unfavorable reaction in winter conditions (Taylor and Craig, 1971; Taylor and Rowley, 1971 and Taylor *et al.*, 1972).

A study on accumulation and movement of minerals in *Paspalum scrobiculatum* L. showed that dry matter increases continuously up to harvest stage with maximum production at milk and dough stages of the crop. Similarly, continuous absorption of the entire nutrient element takes place at all the stages of growth and development. The maximum accumulation of nitrogen takes place between pre-flowering and milk stage of the crop. The phosphorus, calcium and magnesium accumulated between milk and dough stages while potassium between dough and harvest stages of the crop (Khatri and Mehta, 1959). The plants of kodo millet possesses a high degree of tolerance to both copper and zinc (Arora *et al.*, 1999).

Kodo millet genotypes with high leaf area index (LAI), crop growth rate (CGR) and net assimilation rate (NAR) results in high grain yield (Sharma, 1988). While, Koutu (1989) observed that genotypes with moderate LAI and CGR had high biological yield. Since the biological yield determines the grain yield, hence, such genotypes may give high yield coupled with moderate to high harvest index. The genotypes possessing such characteristics were IPS 164, IPS 86, IPS 115, IPS 113, IPS 147 and IPS 112. Nirmala Devi *et al.* (1988) studied physiological parameters and grain yield in 20 genotypes of kodo millet. They reported that LAI at all the stages, dry matter and CGR at flowering and grain filling and NAR at flowering contributed more towards grain yield. They further suggested that these characters might be effective as direct selection for grain yield in kodo millet.

In a study on growth pattern, Rao (1989) did not found significant variation for phenological attributes. Whereas, morphological components, dry matter distribution and growth parameters exhibited different developmental pattern and pathway for growth habit. The morpho-

physiological parameters as well as dry matter distribution were affected by plant densities. The genotypes × plant densities interaction were also significant for growth and biomass distribution. The optimum plant density for high dry matter accumulation in various plant parts and their better conversion from source to sink was 0.6 million/ha. An ideotype of kodo millet should be taller plant with longer internodes, long panicle and high dry matter accumulation in all plant parts. The dough stage was the most critical stage of the crop growth with maximum influence on the yield potential of kodo millet genotypes.

Kodo millet is cultivated in extreme conditions of soil, climate and rainfall, where moisture deficiency is the recurrent feature. The genotypes possessing tolerance to drought thus produce higher grain yield. The efforts should be therefore to identify the morpho-physiological characters related to drought tolerance and better seedling establishment under early season stress. Shashidhar *et al.* (1997) suggested that low stomatal frequency associated with high photosynthetic rates, waxiness of leaves and quick stomatal closer under stress are the characters which can help in avoiding the scarcity of moisture. On other hand, the high rate of imbibitions, high solute potential of the seed and capacity of the seedlings to break the crust in top soils are the important characters for better seedling establishment under early seasonal stress. A thorough investigation is needed to understand the drought resistance mechanism in this crop which can help the breeders in development of high yielding drought tolerant lines of kodo millet.

CHAPTER 3

Genetic Improvement

The genetic improvement work on kodo millet was started before the independence in the country. The first kodo millet improved variety PLR 1 was released in 1942 for the rainfed areas of Tamil Nadu. After the independence, the genetic improvement work was initiated in Madhya Pradesh during 1964 by the financial assistance from the state government. Niwas 1, yet another improved variety was released in 1971 as the outcome of this work for general cultivation in Madhya Pradesh. All India Co-ordinated Millets Improvement Project was though started in 1969, but the work on genetic improvement on kodo millet was intensified after establishment of centres in the country during 1978 with financial assistance from International Development Research Centre, Ottawa, Canada. The improved varieties and production technologies were generated during 1980s under the project. The systematic multidisciplinary improvement work on the crop is getting momentum under All India Co-ordinated Small Millets Improvement Project launched in 1986 by ICAR, New Delhi.

Presently emphasis is being given to (i) the development of high yielding varieties with resistance to biotic and abiotic stresses; (ii) enrichment of germplasm, their critical evaluation for morphological, physiological and biotic and abiotic resistance traits; and (iii) enhancement in available genetic variability through hybridization/mutagenesis for identification of ideotypes suitable for different farming situations.

Recommended improved varieties

A number of varieties with high yield potential and resistance to major diseases and pests has been released for general cultivation in different kodo millet growing states of country. PLR 1 was the first variety followed by CO 1 and Niwas 1. During 1970s, about 10 improved varieties were released for general cultivation, which were CO 2, K 1, JNK 101, JK 1, JK 2, JNK 364, PSC 1, GK 1, CO 3 and IPS 147-1. Among them, K 1, JK 1, JK 2, CO 3 and GK 1 have got the notification status for seed production.

The list of released and notified varieties and their area of adaptation is mentioned in Table 3.

Table 3. Recommended varieties of kodo millet for different states of the country

Variety	Year of release	Institute where developed	Pedigree	Area of adaptation	Yield potential (kg/ha)
K 1	1982	TNAU, Coimbatore	Pure line selection	Tamil Nadu	1,500-1,600
CO 3	1982	TNAU, Coimbatore	Pure line selection	Tamil Nadu	1,300-1,500
JK 1	1982	JNKVV, Jabalpur	Selection from local germplasm	Madhya Pradesh	1,300-1,500
JK 2	1982	JNKVV, Jabalpur	Selection from local germplasm	Madhya Pradesh	1,300-1,500
GK 1	1985	GAU, HMS, Dahod	Selection from local germplasm	Gujarat	1,500-1,600
PSC 1	1985	Project	Selection from local germplasm Co-ordinator cell, Bangalore	Andhra Pradesh, Madhya Pradesh, Gujarat, Karnataka and Uttar Pradesh	1,600-1,800
JK 41	1986	JNKVV, Rewa	Selection from local material	Madhya Pradesh, Andhra Pradesh, Gujarat	2,000-2,200
JK 62	1989	JNKVV, Rewa	Selection from local germplasm	Madhya Pradesh, Andhra Pradesh Gujarat and Bihar	2,000-2,200
JK 76	1991	JNKVV, Rewa	Selection from local germplasm	Madhya Pradesh	1,800-2,200
GPUK 3	1991	Project Co-ordinator cell, Bangalore	Selection from GPLM 826	All States	2,000-2,200
APK 1	1993	TNAU, ARS, Arupukottai	Selection from PSC 5	Tamil Nadu	1,800-2,000
GK 2	1993	GAU, HMS, Dahod	Selection from GPUK 5	Gujarat	1,500-1,600
Vamban 1 (KMV 20)	1996	TNAU, RAS, Pudukottai	Selection from Pali	Tamil Nadu	1,700-1,800
KK 1	1999	CSAUT, Kanpur	Pure line selection from germplasm of dist. Deoria (Uttar Pradesh)	Uttar Pradesh	1,88-2,200
JK 155	2000	JNKVV, Rewa	Selection from germplasm	Karnataka, Madhya Pradesh	2,100-2,200
JK 48	2001	JNKVV, Dindori	Pure line selection	Andhra Pradesh, Madhya Pradesh, Chhattisgarh, Karnataka and Gujarat	2,500-2,700
KK 2	2002	CSAUT, Kanpur	Selection from genetic collection of dist. Balia (Uttar Pradesh)	Uttar Pradesh	2,000-2,300

The salient features of these varieties are given here.

K 1	:	It matures in 100 days. Green plants with profuse tillering and dark brown seeds.
CO 3	:	Semi-erect plants with 5 to 6 tillers/plant. It matures in 110-120 days. The panicles are well exposed with clustered spikelets.
JK 1 (Pali)	:	The plants are semi-erect with heavy tillering, green stem and foliage. Ears are medium with 3–5 fingers and light brown, semi hard, medium size grains. It matures in 110–120 days.
JK 2	:	Semi-erect plant with 9–15 tillers/plant. Green oblong and semi-dense panicles with long fingers. Seeds are dark brown, hard and medium in size. It matures in 110-120 days.
GK 1	:	Variety matures in 115–120 days. Plants medium with glabrous stem, nodes swollen, green leaves, panicles long, grains brown and bold. It is suitable for Western ghats of Gujarat.
PSC 1	:	It matures in 100–105 days. Plant height is 45–60 cm with 6–8 effective tillers. The ears are semi compact with dense spikelets.
JK 41	:	The plants are semi-dwarf and erect. It possess two regular rows of spikelets on the rachis. The variety is highly tolerant to shoot fly and resistant to head smut. It matures in 105–108 days; more suitable for inter/mixed cropping.
JK 62	:	Short stature plants with 45–50 cm height. Leaves are dark green in colour. It matures in 90-100 days. It is resistant to head smut and bacterial blight. It possess tolerance to shoot fly. The seeds are light brown in colour and medium in size. It is suitable for low fertility conditions.
JK 76	:	Dwarf erect plant with 8–15 tillers/plant; extra early in maturity (85–90 days). Seeds are dark-brown and bold having 1,000 grain weight of about 5.4 g. Moderately resistant to shoot fly, recommended for marginal lands, hill tops and shallow soils, where moisture depletes very soon. Also suitable for double cropping.

GPUK 3	:	The plants are dwarf, erect with 6 basal tillers. Top 2–4 nodes produces inflorescence. Compact, partially exerted ear with 2–3 irregular rows of spikelets on rachis. Grains are brown in colour. It matures in 100–105 days. It possess wider adaptability.
APK 1	:	It is an early maturing variety, which matures in 100–102 days.
GK 2	:	The variety matures in 110–112 days. Plants are dwarf with 50–60 cm height. Bold brown grains with non-shattering habit.
Vamban 1 (KMV 20)	:	Semi tall plant with 8–10 tillers/plant. It possess two regular rows of spikelets on rachis. Seeds are bold and brown in colour. It matures in 100–110 days. Long ear heads, dark anthocyanin pigment on leaf, green internodes and brown ear heads. It is resistant to head smut.
KK 1	:	Medium tall plants with almost erect spikes at maturity and free panicles. Recommended for different agro climatic conditions of Uttar Pradesh.
JK 155	:	Semi spreading, medium tall plants with semi compact ears. Early maturing variety with resistant to shoot fly and head smut.
JK 48	:	Erect and pigmented plants with compact ears and 2–4 irregular rows of spikelets on rachis. It matures in days.
KK 2	:	Erect and medium tall plants with green foliage, 20–30 upward panicles, tapering and brown at maturity. Resistant to head smut and tolerant to drought. Also suitable for saline condition.

DONORS FOR ECONOMIC ATTRIBUTES

Genetic resources provide basic raw material for genetic improvement in any particular crop and also helps in reducing the genetic erosion due to spread of high yielding varieties and natural calamities. Realizing the importance of genetic resources in kodo improvement, the first attempt to collect the available germplasm in the country was made in 1961 under PL 480 project on storage, maintenance and distribution of millet

germplasm. A total of 584 germplasm of kodo millet were collected in this programme along with nearly 255 germplasm of other small millets. After that the attempts were made to collect the spectrum of gene pool of kodo millet including land races and improved varieties from different parts of the country. As a result, the germplasm unit of AICRP on Small millets at Bangalore is maintaining 1,044 germplasm of this crop. Similarly, a total of 433 and 544 germplasm of kodo millet are maintained at NBPGR, New Delhi and ICRISAT, Hyderabad, respectively. These genotypes are under process of characterisation, classification and cataloguing. Recently, the Project Co-ordinating Cell of AICRP on Small Millets has published a catalogue of kodo millet germplasm after very elaborate evaluation and characterization, as per international descriptors. Besides this, the donors for biotic resistance and economic germplasm has been identified for the specific attributes through quantitative quantification by various scientists of the country. The promising genotypes are presented in Table 4 for

Table 4. Economic genetic resources of kodo millet

Economic attributes	Donors	Reference
Tolerant to head smut	JK 41, JK 62, JNK 117, KMV 8 and RPS 136-1	Verma (1989) and Yadava (1993)
	GPLM 717, 779 and 786	Jain *et al.* (1993)
	DPS 34, 77, 159, RPS 136-1 and KMV 20	Jain (1995)
Tolerant to shoot fly	IPS 6, 32, 110, 131, 142, 178, RPS 40-1, 40-2, 62-3, 72-2, 120-1 and Keharpur	Murthy and Harinarayana (1989)
	IPS 147-1, JK 41, RPS-140-1 and RPS 136-1	Singh *et al.* (1990)
Wider adaptability and yield stability	JK 41, JK 62 and IPS 147-1	Mishra *et al.* (1987) and Tikle and Yadava (1992)
	KMV 20 and JNK 364	Yadava (1993) and Rao and Shrivastava (1997)
	KK 1, KMV 20 and GPUK 3	Singh *et al.* (1997) and Yadava *et al.* (1996)
Early maturity	JK 76	Tikle and Yadava (1992)
Protogynus nature of flowering	KM 32	Yadava (1997a)
Protein stability	IPS 112, 147 and 147-1	Koutu (1989)

various traits. These genotypes could be utilized in breeding programme aimed at development of new genetic variants and recombinants for facilitating selection in desirable direction. In kodo millet, the rate and accumulation of spontaneous mutants and slow release of hidden genetic variability through natural cross-pollination, recombination and segregation regulated by cytological homeostasis is major source of variation. Hence, efforts should be made jointly by the AICRP on Small Millets, Bangalore, and NBPGR, New Delhi, for collection, evaluation and cataloguing of these germplasm.

GENETIC STUDIES

Available genetic variability and their quantification is the pre-requisite for any crop improvement programme. However, the success of breeding programme depends on sound planning, appropriate selection of parents, their correct utilization and meaningful interpretation of results. Traditionally the selection of parents was based on local adaptation, character compensations and random selection to produce recombinants through breeding techniques, but several biometrical techniques are recently available for selection of parents and to decide the nature of selection criteria in segregating generations. Some of these techniques have been used to evaluate their practical utility for genetic improvement in grain yield of kodo millet. The present status of genetic studies on this crop are given here.

Genetic diversity

The diversity is the gift of nature. The plant genetic diversity is of immense value in selecting the parents either to exploit heterosis or to get desirable recombinants and transgressive segregants. The multivariate analysis based on Mahalanobis D^2 statistics has been found an effective tool for quantification of genetic divergence among the population. However, its use becomes limited for classifying the unreplicated data and huge germplasm collection for several characters. The use of non-hierarchical Euclidean cluster analysis suggested by Beale (1969) overcome these limitations. Both the techniques have been used for quantification of genetically diverse germplasm in kodo millet.

Dhagat (1978) was the first who studied the genetic diversity among 6 exotic and 90 indigenous germplasm of kodo millet. He observed no relation among genetic and geographic diversity. However, the germplasm from Georgia, Transvaal, Paraguay, Argentina and India were grouped in different clusters indicating substantial diversity among the genotypes studied by them. He also observed that vegetative characters like days to

Fig. 4. Members of QRT observing kodo millet germplasm at Rewa (Madhya Pradesh)
Source: All India Co-ordinated Research Project on Small Millets, Rewa (Madhya Pradesh)

50% flowering, days to maturity, plant height and straw yield were the important factors in differentiation among the germplasm from different geographic regions.

Parihar (1985) studied the genetic divergence among 100 genotypes of kodo millet through D^2 analysis. Based on 12 characters, the genotypes were grouped into 15 clusters. The cluster I and II possessed the maximum number of genotypes while, cluster IX to XV were monogenotypic. The relation between geographic and genetic diversity was not evident. However, the germplasm numbers 337, 499, 559, 78 and 144 were quite divergent as they formed separate individual cluster.

Two hundred sixty one germplasm comprising 133 early and 128 late maturing were evaluated at Rewa centre (Fig. 4) during 1993-94 to study the genetic divergence by non-hierarchical cluster analysis. The early and late maturing genotypes were grouped in 7 and 16 clusters, respectively (Table 5). It indicated that genetic diversity was greater in late maturing genotypes as compared to early maturing. Cluster IV in early maturing and cluster XIV followed by II, V and X in late maturity group possessed the maximum number of genotypes. Among the late maturing genotypes, GPLM 170 was the most divergent and formed the individual cluster. The estimates of inter-cluster distances ranged from 1.97 to 12.73 and 1.78 to

Table 5. Cluster composition of genotypes belonging to two maturity groups in kodo millet

Clusters	Early maturing		Late maturing	
	No.	Genotypes	No.	Genotypes
I	24	GPLMP 8, 37, 137, 160, 239, 573, 579, 603, 741, 747, 783, 791, 815, 816, 824, 851, 969, 977, 980, 983, 987, 990, 1009, and 1017	1	GPLMP 170
II	23	GPLMP 314, 500, 505, 546, 547, 601, 605, 608, 726, 772, 780, 790, 812, 813, 822, 825, 831, 834, 845, 909, 939, 979, and 1018	13	GPLMP 39, 42, 64, 78, 81, 86, 89, 90, 176, 177, 181, 196 and 1019
III	17	GPLMP 134, 137, 163, 217, 218, 377, 748, 752, 755, 760, 761, 764, 782, 870, 970, 995 and 1003	3	GPLMP 669, 677 and 683
IV	30	GPLMP 68, 73, 76, 77, 164, 167, 189, 265, 280, 744, 765, 785, 788, 804, 814, 826, 827, 838, 842, 853, 858, 861, 864, 891, 899, 902, 910, 926, 961 and 985	8	GPLMP 54, 301, 302, 304, 479, 482, 485 and 936.
V	27	GPLMP 102, 105, 111, 117, 140, 141, 144, 147, 150, 152, 154, 155, 162, 165, 166, 168, 172, 175, 190, 191, 252, 255, 260, 731, 738 and 595	13	GPLMP 108, 113, 122, 124, 126, 128, 129, 226, 229, 231, 232 and 406
VI	11	GPLMP 247, 251, 512, 801, 806, 865, 875, 880, 893, 897, and 900	6	GPLMP 550, 562, 582, 584, 594 and 840
VII	1	GPLMP 810	10	GPLMP 297, 332, 333, 337, 339, 350, 380, 390, 460 and 463
VIII	-	-	11	GPLMP 52, 103, 169, 202, 213, 249, 257, 387, 407, 927 and 928
IX	-	-	5	GPLMP 135, 188, 451, 883 and 1008
X	-	-	13	GPLMP 267, 270, 447, 599, 610,628, 629, 835, 950, 957 and 958

(Table 5 *continued*)

(Table 5 *concluded*)

Clusters	Early maturing		Late maturing	
	No.	Genotypes	No.	Genotypes
XI	-	-	4	GPLMP 344, 345, 996 and 1002
XII	-	-	8	GPLMP 307, 308, 319, 324, 349, 385, 641 and 664
XIII	-	-	12	GPLMP 10, 14, 192, 201, 224, 225, 281, 361, 660, 853, 854 and 1000
XIV	-	-	16	GPLMP 5, 6, 19, 29, 33, 43, 45, 57, 58, 59, 66, 67, 742, 777, 925 and 1011
XV	-	-	3	GPLMP 133, 974 and 1021
XVI	-	-	2	GPLMP 859 and 865

9.08 in early and late maturing genotypes, respectively (Table 6). The cluster IV and VII were most divergent in early group while, I and XVI possess maximum inter-cluster distance in late group of the genotypes. It suggest that the genotypes grouped in these clusters were most divergent. Cluster VI possessed the highest mean value for grain yield, biological yield and peduncle length (Table 7) in both group. Cluster IV had maximum plant height in late group while, cluster VI had maximum plant height in early group. In general, all the characters exhibited considerable contribution towards genetic divergence. However, the per cent contribution was maximum by plant height followed by tillers/plant, flag leaf length, peduncle length and ear length in both group (Table 8). The least contribution towards divergence was observed by harvest index. The study thus revealed the existence of significant diversity in the present material. Hence, hybridization involving genetically diverse parents belonging to different clusters separated by high inter cluster distance is suggested for achieving the desirable recombinants.

Genetic variability

Quantification of genetic variability in its heritable and non-heritable components provide many avenues for genetic amelioration of a particular crop. Janoria (1963) was the first to study the variability in different strains of kodo millet collected from Madhya Pradesh and classified them on the basis of leaf colour, spike structure and density along with grain yield.

Table 6. Average intra- and inter-cluster distances for early (E) and late (L) maturing genotypes of kodo millet

Clusters		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI
I	E	**1.08**	2.03	2.79	1.99	2.38	3.95	11.99	-	-	-	-	-	-	-	-	-
	L	**0.01**	5.68	7.75	7.47	6.42	7.12	7.49	6.92	5.53	6.45	7.42	7.48	6.28	6.75	7.59	9.08
II	E		**1.78**	3.45	1.97	3.50	3.08	11.76	-	-	-	-	-	-	-	-	-
	L		**1.39**	5.61	4.14	2.49	3.02	4.00	2.57	2.66	2.49	3.81	4.47	1.99	2.49	4.86	5.58
III	E			**1.97**	2.42	2.85	5.15	11.78	-	-	-	-	-	-	-	-	-
	L			**1.28**	2.88	5.31	6.41	2.73	4.23	4.73	4.42	3.88	2.05	4.19	4.99	5.09	5.21
IV	E				**1.70**	2.39	2.96	11.59	-	-	-	-	-	-	-	-	-
	L				**1.68**	5.00	4.17	3.49	2.96	4.64	3.59	4.21	2.38	3.60	3.61	6.09	3.51
V	E					**2.09**	3.95	12.73	-	-	-	-	-	-	-	-	-
	L					**1.44**	5.04	2.92	2.92	2.30	3.09	3.15	4.50	1.78	3.67	2.78	6.71
VI	E						**2.01**	12.04	-	-	-	-	-	-	-	-	-
	L						**1.28**	5.45	3.18	5.01	3.09	5.31	4.81	3.98	2.91	7.21	3.75
VII	E							**0.00**	-	-	-	-	-	-	-	-	-
	L							**1.51**	2.66	3.07	2.89	2.13	2.16	2.25	3.86	2.99	5.41
VIII	E								**-**	-	-	-	-	-	-	-	-
	L								**1.49**	3.59	2.08	3.55	2.89	2.04	2.68	4.83	4.11
IX	E									**-**	-	-	-	-	-	-	-
	L									**1.53**	2.68	2.19	3.89	2.08	3.74	3.15	6.62
X	E										**-**	-	-	-	-	-	-
	L										**1.28**	2.55	2.76	1.78	2.14	4.45	4.25
XI	E											**-**	-	-	-	-	-
	L											**1.16**	2.85	2.38	3.78	2.97	5.84
XII	E												**-**	-	-	-	-
	L												**1.17**	3.21	3.85	4.91	3.98
XIII	E													**-**	-	-	-
	L													**1.28**	2.15	3.32	5.18
XIV	E														**-**	-	-
	L														**1.68**	5.15	3.93
XV	E															**-**	-
	L															**0.82**	7.92
XVI	E																**-**
	L																**0.00**

Bold figures denote the intra-cluster distances

Table 7. Intra-cluster group mean for eight characters in early (E) and late (L) maturing genotypes of kodo millet

Clusters		Plant height	Tillers/ plant	Flag leaf length	Peduncle length	Ear length	Grain yield/ plant	Biological yield/ plant	Harvest index
I	E	56.38	3.69	24.09	22.07	8.14	2.11	6.68	32.16
	L	54.45	3.43	19.65	12.90	12.00	2.56	7.17	51.60
II	E	63.05	2.97	24.07	24.64	8.62	2.79	7.74	36.46
	L	58.10	3.52	19.95	19.29	7.55	3.34	8.78	38.23
III	E	49.17	2.37	21.66	19.94	8.05	1.54	4.45	35.10
	L	76.90	2.20	22.50	22.57	13.02	1.65	7.56	21.73
IV	E	49.17	2.37	21.66	19.94	8.05	1.54	4.45	35.10
	L	76.90	2.20	22.50	22.57	13.02	1.62	7.56	21.73
V	E	51.82	3.59	19.52	19.38	7.49	2.53	1.87	31.07
	L	50.67	3.37	18.30	18.37	7.66	1.86	6.08	30.66
VI	E	59.30	3.08	22.79	22.57	8.52	4.94	12.58	39.44
	L	62.97	4.54	23.51	24.62	8.19	4.35	11.50	37.73
VII	E	52.65	3.00	28.80	12.25	15.95	1.67	5.71	53.80
	L	67.60	2.91	20.65	22.32	9.67	1.32	5.85	22.92
VIII	E	-	-	-	-	-	-	-	-
	L	62.83	4.13	19.97	22.88	9.33	2.48	9.16	27.63
IX	E	-	-	-	-	-	-	-	--
	L	54.96	2.32	20.68	20.43	8.41	2.19	5.47	40.15
X	E	-	-	-	-	-	-	-	-
	L	59.84	3.61	24.30	23.84	8.77	2.56	7.37	34.74
XI	E	-	-	-	-	-	-	-	-
	L	57.23	2.07	23.40	24.06	8.56	1.67	5.8	28.97
XII	E	-	-	-	-	-	-	-	-
	L	79.90	2.96	23.01	25.99	10.56	1.94	7.03	27.59
XIII	E	-	-	-	-	-	-	-	-
	L	59.72	3.24	21.93	19.56	8.43	2.26	7.43	30.43
XIV	E	-	-	-	-	-	-	-	-
	L	65.10	3.77	26.30	19.26	8.14	3.01	9.77	31.13
XV	E	-	-	-	-	-	-	-	-
	L	50.52	2.25	20.85	17.48	8.20	0.68	2.86	24.08
XVI	E	-	-	-	-	-	-	-	-
	L	84.90	4.54	28.32	27.23	10.15	3.1	12.74	25.10

Amawate (1965), Satpute (1966), Tiwari and Janoria (1967), Amawate and Dabral (1970), Choudhary and Singh (1970) and Rao (1991) also observed wide range of variability for morphological characters and grain yield in land races of Madhya Pradesh. Verma and Satpute (1969) and Ahluwalia

Table 8. Per cent contribution of various characters towards genetic divergence in kodo millet

Variables	Per cent contribution of variables	
	Early group	Late group
Plant height	29.85	31.94
Tillers/ plant	22.20	28.75
Flag ear length	15.18	10.68
Peduncle length	11.79	9.8
Ear length	8.80	8.21
Grain yield/plant	6.93	6.18
Biological yield/plant	4.86	3.77
Harvest index	0.39	0.59

et al. (1970) also recorded high heritable variability for days to flowering, ears/plant, and tillers/plant in kodo millet. The magnitude of phenotypic coefficient of variation was high for dry matter production, grain yield/ plant, panicle number/plant and basal tillers/plant whereas it was low for developmental traits like days to flowering and days to maturity in kodo millet. Dhagat *et al.* (1971), Dhagat (1978), Parihar (1985), Sharma (1988), Rao and Tiwari (1988), Yasin *et al.* (1988) and Kandaswany *et al.* (1990) found maximum heritable variation for tillers/plant, ears/plant, ear weight, grains/ear, fodder yield and grain yield. They also noted low amount of heritable variation for plant height and phenological attributes, days to ear emergence, days to flowering and period from flowering to maturity in the genotypes of kodo millet studied by them.

Leaf area index (LAI) at all stages, crop growth rate (CGR) at flowering and grain filling along with net assimilation rate (NAR) at flowering showed high heritability coupled with moderate to high genetic advance whereas the low magnitude of these genetic parameters was recorded for days to flowering, tillers/plant and leaf area duration in the genotypes of kodo millet. High heritability coupled with moderate to high genetic advance for LAI, NAR, dry matter production and CGR at flowering and grain filling along with days to flowering and maturity indicated that these physico component characters are governed mainly by additive genes and can be improved through conventional breeding methods (Nirmala Devi *et al.* 1988).

Phenotypic coefficient of variation for physiological attributes over plant densities was also estimated by Rao (1989) in kodo millet. The genotypes reflect high variability due to plant densities in various physiological components like mother, other shoots and their respective nodal shoots at

all the stages of growth. However, the genotypes did not showed much variation for dry matter accumulation of mother and other shoots at a given plant densities. It reflects that kodo millet genotypes used by Rao (1989) did not have much plasticity for biomass accumulation in various shoots and their components.

Table 9. Parameters of genetic variability for protein, mineral contents in kodo millet over environments

Character	Mean	Range		PCV	GCV	h^2	GA
		Minimum	Maximum				
Jabalpur							
Carbohydrate	69.16	63.46	78.18	5.55	5.54	99.63	11.36
Protein	5.42	3.13	5.42	11.99	11.94	99.24	24.53
Cu (ppm)	22.87	3.31	44.00	26.73	26.59	98.70	79.84
Zn (ppm)	24.84	11.03	40.37	34.37	34.36	99.90	70.86
Fe (ppm)	8.59	5.31	13.30	35.04	32.99	99.60	67.86
Mn (ppm)	54.22	34.43	70.22	19.82	19.82	99.99	38.69
Dindori							
Carbohydrate	69.20	62.30	74.88	5.46	5.19	90.61	10.19
Protein	5.43	3.13	9.08	15.73	15.62	98.80	32.02
Cu (ppm)	11.32	3.20	44.11	1.07	0.97	83.50	1.84
Zn (ppm)	24.59	11.03	40.32	34.26	34.25	99.90	70.55
Fe (ppm)	8.73	5.10	17.78	23.30	23.29	99.90	47.95
Mn (ppm)	54.43	35.12	68.07	19.79	19.78	99.90	40.75
Chhindwara							
Carbohydrate	69.23	63.72	75.16	5.57	5.57	99.86	11.50
Protein	5.58	3.08	9.63	18.64	18.50	98.60	37.87
Cu (ppm)	11.29	3.07	42.51	30.31	29.87	97.10	60.63
Zn (ppm)	24.98	11.96	41.03	25.42	25.41	99.90	52.52
Fe (ppm)	8.74	5.34	17.91	32.44	32.39	99.70	66.59
Mn (ppm)	54.55	35.29	69.68	19.93	19.92	99.90	41.10
Rewa							
Carbohydrate	68.98	62.99	75.12	5.98	5.22	76.01	9.36
Protein	5.55	3.09	9.09	9.81	9.64	96.60	19.51
Cu (ppm)	11.36	3.09	44.04	20.15	19.94	97.90	40.63
Zn (ppm)	24.89	10.96	42.06	20.83	20.28	98.90	52.99
Fe (ppm)	8.82	5.32	18.08	32.72	32.30	97.40	65.66
Mn (ppm)	53.86	34.90	68.91	22.47	18.00	64.20	29.72
Pooled							
Carbohydrate	69.12	62.61	75.17	5.58	5.39	93.10	10.70
Protein	5.50	3.13	9.21	37.42	37.27	99.17	76.54
Cu (ppm)	11.29	3.31	44.16	35.35	35.34	99.90	72.75
Zn (ppm)	24.20	11.02	40.58	34.74	34.42	98.10	70.78
Fe (ppm)	8.72	5.70	17.74	32.60	32.09	99.00	66.51
Mn (ppm)	54.00	36.41	70.88	20.53	19.41	89.40	37.52

Source: Koutu (1989)

Being a rich source of minerals, the attempts have also been made to determine the genetic variability for protein and mineral constituents of the grains in kodo millet. Koutu (1989) studied the heritable variation for quality attributes in kodo millet genotypes by evaluating them at four locations in different agro-climatic zones of Madhya Pradesh. The range of variation was 62.61 to 75.17% for carbohydrate, 3.13 to 9.21% for protein, 3.31 to 44.16 ppm for Cu, 11.02 to 40.58 ppm for Zn, 5.70 to 17.74 ppm for Fe and 36.41 to 70.88 ppm for Mn over the locations (Table 9). The magnitude of PCV was higher than GCV with maximum estimate for protein followed by Cu, Zn, Fe and Mn. While, low estimate in variability was noted in carbohydrate content. The magnitude of heritability and genetic advance were high for all the nutritional traits except carbohydrate which showed high heritability coupled with low GA as per cent of mean. It indicated that these traits are under control of additive genes. Hence, selection based on phenotypic performance would be more effective. The genotypes IPS 115, 88, 177, 115, 85 and 202 exhibited the highest while, IPS 119, 192, 138, 112, 104 and 199 showed lowest estimates of protein, carbohydrate, Cu, Zn, Fe and Mn, respectively.

An overall consideration of studies pertaining to genetic variation revealed that a wide range of variation for yield and its components, physiological parameters and nutritional quality traits exists in the germplasm presently collected from different parts of the country. However, there is an ample possibility to enrich the variability for economic traits through vigorous collection of variable lines produced through spontaneous mutations and natural hybridization. The majority of studies have been conducted based on single environment testing. Hence, efforts should be made to determine the real variability after deleting the genotype × environment component of variability from total variation by evaluating the genotypes in multi environmental conditions in kodo millet.

Stability analysis

Kodo millet is cultivated in unbounded uplands and from the slope to plateau of hills where microclimates such as soil type, soil depth, soil moisture retention capacity, soil fertility and even altitude varies considerably. These complex farming conditions needs varieties possessing wider adaptability to enhance and stabilize the production. Recently, regression analysis technique developed by Ebertart and Russell (1966) is available to partitioned the genotype × environment interaction into its linear and non linear components and thus help in identification of varieties having yield stability. The technique has been adopted to test the adaptability of genotypes in kodo millet also.

Choudhary and Singh (1970) was the first who estimated the variety × environment interaction by testing the kodo millet genotypes under two levels of fertility. They found significant influence of fertility levels on the expression of grain yield and its attributing characters. Dhagat *et al.* (1975) determines the stability in grain yield by testing the genotypes of kodo millet at two locations namely Dindori and Jabalpur, in two subsequent years. They reported that Niwas 1 was stable for seed yield and tillers/plant Whereas IPS 364 and IPS 92 exhibited stability in ears/plant and ear length.

The high yielding genotypes RPS 62-3, RPS 76 and RPS 41 released as JK 62, JK 76 and JK 41, respectively showed stability in yield under rainfed low fertility conditions. The genotypes RPS 128-1, RPS 119-1 and JNK 364 respond to improved environmental conditions (Mishra *et al.*, 1987). Grain yield stability in kodo millet was also worked out by Dastagiraiah and Kumar (1990) and Koutu *et al.* (1993b) under rainfed conditions. The kodo millet genotypes JK 41, IPS 147-1, PSC 9 and PSC 2 possessed wider adaptability under varying soil type (Skeleton gravely and red and black soils) and fertility levels of 0 and 20 kg N/ha in Madhya Pradesh (Tikle and Yadava, 1992), whereas PSC 1, PSC 9, PSC 8 and JNK 364 exhibited their suitability for grain yield under high fertility black soil conditions. The genotypes GPUK 3, DPS 349 and ICK 28 also exhibited wider adaptability and stability for grain yield and harvest index. While PSC 1 was found responsive towards favorable farming conditions for optimum grain yield based on their three years testing at Rewa, Dindori and Jagadalpur in Madhya Pradesh (Yadava *et al.*, 1996). KMV 20 and IGBKK 3 were also found stable for grain yield and its component characters (Rao and Shrivastava, 1997) while a high-yielding variety RPS 136-1 was responsive to high stressed conditions with its better performance in skeleton gravely soils of Madhya Pradesh (Singh *et al.*, 1997). Kodo millet varieties possessing high yield and wider adaptability should be popularised to enhance and stabilize the productivity of kodo millet. These genotypes could also be used in breeding programme in order to generate transgressive variation for high yield with stability. Stability in protein and starch content of the grains in 30 genotypes of kodo millet has been determined by evaluating the genotypes at four locations namely Rewa Jabalpur, Dindori and Chhindwara in Madhya Pradesh (Koutu, 1989). The mean, regression coefficient (bi) and deviation from regression (S^2d) varied considerably among the genotypes for protein and starch content of the grains suggesting that these nutritional parameters were influenced by the environmental conditions prevailed at different locations (Table 10). IPS 136 yielded high protein (9.05%) but it was responsive and stable

Table 10. Stability parameters for protein and starch content of the grains in kodo millet

Genotypes	Protein content of grain			Starch content of grain		
	Mean	bi	S^2d	Mean	bi	S^2d
IPS 199	3.13	-0.067	-0.063	73.42	0.025	-0.568
IPS 149	3.24	-0.924	-0.061	71.91	-0.005	-0.556
IPS 105	4.12	1.476	-0.046	72.09	1.129	-0.555
IPS 163	3.03	1.547	-0.036	68.79	1.301	-0.558
IPS 110	3.19	0.253	-0.043	72.10	-0.981	-0.540
IPS 13	3.10	0.245	-0.054	70.16	0.438	-0.568
IPS 88	3.61	1.227	-0.055	75.17	0.004	-0.457
IPS 113	6.38	3.870	-0.062	67.21	0.086	-0.562
IPS 167	3.17	-0.767	-0.062	72.21	-0.901	-0.552
IPS 194	3.18	2.045	-0.025	71.26	-1.373	-0.561
IPS 76	3.94	4.858	0.065	74.63	0.964	-0.424
IPS 65	3.36	1.311	0.021	74.36	-1.315	-0.492
IPS 177	3.78	-3.182	-0.059	73.38	-1.824	-0.472
IPS 164	3.24	1.276	-0.057	72.59	2.084	0.304
IPS 86	7.08	5.611	0.408	65.81	2.373	3.752
IPS 147	7.80	0.873	-0.001	65.08	-0.434	-0.407
IPS 109	7.38	-1.457	0.080	63.79	0.210	-0.527
IPS 183	6.25	-1.863	0.025	67.52	-3.251	1.573
IPS 200	6.30	0.753	-0.061	67.71	2.263	-0.314
IPS 147-1	7.35	1.152	0.144	66.07	4.808	-0.363
IPS 198	6.31	0.706	-0.015	68.01	-0.346	-0.301
IPS 202	6.50	2.294	-0.031	68.97	0.193	-0.326
IPS 112	7.51	0.889	-0.054	70.16	1.316	-0.212
IPS 66	7.91	-0.320	-0.049	67.10	0.180	-0.400
IPS 107	4.61	-3.992	0.112	73.12	-3.359	1.652
IPS 161	7.19	6.298	0.050	65.74	1.952	1.695
IPS 192	8.18	2.007	-0.060	62.78	-2.408	-0.070
IPS 138	8.20	0.428	-0.062	63.91	0.037	-0.292
IPS 119	7.29	-0.157	-0.006	64.61	1.914	-0.413
IPS 136	9.05	5.224	0.095	65.40	0.054	-0.354

Source: Koutu (1989)

towards favourable conditions. Similarly, the highest starch content yielding genotype IPS 88 was average responsive and stable. The genotype IPS 112, IPS 147 and IPS 147-1 for protein content and IPS 76, IPS 13 and IPS 105 for starch content were found average responsive and stable. Nine genotypes for protein content and 11 genotypes for starch content exhibited

their stability under low management conditions having negative estimates of regression coefficient (Koutu *et al.*, 1993a).

Correlation and path coefficient analysis

The grain yield, a complex trait is known to be governed by many genes and highly influenced by environmental fluctuations. Hence, direct selection based on yield *per se* would not much effective. On other hand, the yield factors are governed by comparatively less number of genes and less susceptible to environmental conditions. The selection based on yield factors has thus found more effective in achieving the goal. Hence, attempts have been made to determine the yield factors through correlation and path coefficient analyses in kodo millet as early as by Amawate (1965), Dhagat *et al.* (1971) and Dhagat (1978).

Association analysis carried out by Verma and Singh (1982) indicates that plant height was positively correlated with grain yield in early and medium maturing genotypes of kodo millet. In early genotypes, plant height also showed positive correlation with panicle length but it was negatively correlated with 1,000 grain weight. Path analysis revealed that only plant height had direct influenced on grain yield in all maturity groups. The panicle length contributed indirectly via plant height towards grain yield. Parihar (1985) observed significant positive correlation between grain yield and days to flowering, days to maturity, plant height, grain-straw ratio, fodder yield 1,000 grain weight and grains/panicle. All these characters also exhibited positive association with fodder yield. Path analysis revealed that fodder yield, grain-straw ratio, fingers/ear and days to flowering are the major components of grain yield in kodo millet.

Significant positive association of grain yield with tillers/plant, finger/ear, biological yield and harvest index was noted by Rao and Tiwari (1988). Tillers/plant showed significant positive association with ears/plant and ear length. While fingers/ear, ear length and days to flowering are also positively and significantly associated among themselves. Yasin *et al.* (1988) found significant positive association between productive tillers/plant and grain yield. Kandaswamy and Manoharan (1993) and Rao *et al.* (1994) indicated that developmental traits mainly determine the grain yield in kodo millet.

As regards the association of physiological parameters with grain yield, Nirmala Devi *et al.* (1988) reported that biological yield, NAR, CGR and dry matter production had significant positive association with grain yield at flowering and grain filling stages. The relative selection efficiency (RSE) was high for NAR at flowering followed by tillers/plant.

Our studies at Rewa with 261 germplasm divided into two groups

namely early (< 100 days) and late (> 100 days) revealed that plant height, tillers/plant and biological yield had significant positive association with grain yield in early maturing genotypes, while plant height, tillers/plant, flag leaf length and biological yield exhibited significant positive association with grain yield in late maturing genotypes of kodo millet (Table 11). Path analysis indicated that ear length, biological yield and tillers/plant in early maturing genotypes, while biological yield, harvest index, peduncle length and plant height in late maturing genotypes are the main components of grain yield in kodo millet (Table 12). An over all assessment of yield factors based on correlation and path analyses revealed that tillers/plant, plant height, panicle length and biological yield are the major yield determining factors in kodo millet. Among the physiological parameters, NAR, CGR, dry matter production and conversion efficiency of source to sink (HI) mainly determine the grain yield. Thus the indirect selection on the basis of these yield components in form of selection indices can be advantageous for genetic improvement in grain yield of kodo millet.

Table 11. Correlation coefficients among seed yield and its attributing characters in early (upper diagonal) and late (lower diagonal) maturing genotypes of kodo millet

Clusters	Plant height	Tillers/ plant	Flag leaf length	Peduncle length	Ear length	Biological yield / plant	Grain yield/ plant	Harvest index
Plant height	P	0.043	0.177*	0.359**	0.281**	0.229**	0.225**	0.024
	G	0.638	0.290	0.754	0.458	0.639	0.642	0.153
Tillers/plant	-0.025	P	-0.080	-0.038	-0.095	0.127	0.247**	-0.137
	-0.133	G	-0.015	0.226	0.178	0.043	0.252	-0.416
Flag leaf	0.211*	0.100	P	0.109	0.273**	-0.046	-0.089	0.141
length	0.461	0.726	G	0.494	0.551	0.113	0.027	0.368
Peduncle	0.444**	0.058	0.196*	P	-0.052	0.138	0.064	-0.139
length	0.482	0.172	0.347	G	0.500	0.550	0.447	0.230
Ear length	0.565**	-0.116	0.082	0.311**	P	-0.033	-0.037	0.572**
	0.760	-0.652	0.280	0.698	G	0.380	0.268	0.338
Biological	0.097	0.412**	0.179*	0.089	-0.166	P	0.876**	0.224**
yield/ plant	0.081	0.848	0.455	0.071	-0.222	G	0.864	0.436
Grain yield/	0.309**	0.381**	0.199*	0.161	0.045	0.792**	P	-0.075
plant	0.528	0.704	0.534	0.381	0.230	0.678	G	-0.065
Harvest	-0.245**	0.156	0.020	-0.229**	-0.083	0.404**	-0.070	P
index	-0.383	0.359	0.009	-0.254	-0.588	0.765	0.056	G

*P=0.5; **P=0.01; P, Phenotypic; G, Genotypic.
Source: Unpublished data of H.S. Yadava

Table 12. Direct and indirect effects of yield components on grain yield in early and late maturing genotypes of kodo millet

Clusters		Plant height	Tillers/ plant	Flag leaf length	Peduncle length	Ear length	Biological yield / plant	Harvest index	Correlation with seed yield
Plant height	E	**-0.030**	0.003	-0.006	-0.037	0.077	0.228	-0.011	0.225**
	L	**0.036**	0.000	-0.001	0.054	-0.124	0.249	-0.117	0.097
Tillers/ plant	E	-0.001	**0.076**	0.003	0.004	-0.026	0.127	0.062	0.247**
	L	-0.001	**-0.001**	0.000	0.007	0.025	0.307	0.075	0.412**
Flag leaf length	E	-0.005	-0.006	**-0.032**	-0.011	0.075	-0.046	-0.064	-0.089
	L	0.008	0.000	**-0.004**	0.024	-0.018	0.160	0.010	0.179*
Peduncle length	E	-0.011	-0.003	-0.003	**-0.104**	-0.014	0.137	0.063	0.064
	L	0.016	0.000	-0.001	**0.122**	-0.068	0.130	-0.109	0.098
Ear length	E	-0.008	-0.007	-0.009	0.005	**0.275**	-0.033	-0.260	-0.037
	L	0.020	0.000	0.000	0.038	**-0.220**	0.036	-0.040	-0.166
Biological yield/ plant	E	-0.007	0.010	0.001	-0.014	-0.009	**0.996**	-0.102	0.876**
	L	0.011	0.000	-0.001	0.020	-0.010	**0.806**	-0.034	0.792**
Harvest index	E	-0.001	-0.011	-0.004	0.014	0.157	0.224	**-0.455**	-0.075
	L	-0.009	0.000	0.000	-0.028	0.018	-0.056	**-0.479**	0.404**

*P=0.05; **P=0.01; bold figures denote the direct effect; residual effect E (Early)=0.0948; L (Late)=0.1191.

Source: Unpublished data of H.S. Yadava

Table 13. Best 5 genotypes of kodo millet based on selection indices

Genotype	Varietal index for grain yield	Rank
Early maturing		
GPLM 407	59.81	I
GPLM 810	51.63	II
GPLM 247	50.40	III
GPLM 547	47.59	IV
GPLM 900	46.46	V
Late maturing		
GPLM 495	70.52	I
GPLM 54	63.29	II
GPLM 302	61.56	III
GPLM 58	57.96	IV
GPLM 927	56.39	V

Source: Unpublished data of H.S. Yadava

Selection indices

Among the methods available for selection of parents, selection indices has been found most appropriate method to know the genetic merits of each genotype based on linear combination of yield factors. Verma and Singh (1982) computed the multiple regression equation and suggested that panicle length and 1,000 grain weight accounts for substantial variation in grain yield of kodo millet. The promising genotypes possessing higher estimates of selection indices have been identified both in early and late maturing genotypes (Table 13). These genotypes could be utilized in breeding programme.

BREEDING METHODS

The varieties of kodo millet so far released are mainly developed through selection from land races or germplasm. However, the mutation and recombination breeding has got momentum in recent past for genetic enhancement in grain yield along with resistant to biotic stresses.

SELECTION BREEDING

Introduction and selection

The movement of new varieties, wild relatives and new species of a crop from one environment to other or within or between the countries is known as introduction. Recently released kodo millet varieties namely APK 1, GK 2 and KMV 20 are the product of selection from the germplasm introduced in different agro-ecosystem. The ample possibility thus exists for improvement in kodo millet through introduction and selection. A good number of germplasm are being maintained at the germplasm unit of All India Co-ordinated Research Project on Small millets, Bangalore, National Bureau of Plant Genetic Resources, New Delhi and International Crops Research Institute for the Semi-Arid Tropics, Hyderabad. These gene pool can be introduce any where in the world to know their potentiality under different agro-climatic zones. Rewa centre has already developed the early maturing and high yielding line (JK 155) from the germplasm introduced from the Bangalore in 1993. Thus, the possibility for multilocation evaluation and documentation of germplasm deserves priority to identify the sources of useful genes and to accelerate the process of improvement in presently needed direction.

Pure line selection

Pure line selection has been extensively practiced in India for improvement in kodo millet. Single plant selection from land races and cultivated varieties, their evaluation for economic characters like earliness,

resistance to biotic stresses and high yield have resulted in release of more than dozen varieties of kodo millet. Breeding for high yield (Harinarayana, 1989), earliness (Singh *et al.*, 1993), resistance to head smut and shoot fly (Verma, 1989; Singh *et al.*, 1990; Yadava and Jain, 1996) have been achieved through this method to certain extent but there is good scope for improvement in genetic yield potential through increase in growth rate, food conservation efficiency from source to sink and yield attributing characters along with resistance/tolerance to environmental stresses like low soil moisture and soil fertility and biotic stresses i.e. diseases, insect pest and parasitic weeds. Since the success of pure line selection mostly depends on the rate and accumulation of spontaneous mutation and slow release of hidden genetic variability through natural cross pollination, recombination resulted from cytological homoeostasis (Navale *et al.*, 1984).

RECOMBINATION BREEDING

The difficulty in emasculation and pollination due to small and delicate spikelets combined with brittleness of rachis have resulted a slow progress in recombination breeding of kodo millet. However, the methods of hybridization and selection have been standardized in recent past. These are being extensively used for creation of variability and selection of transgressive segregates from advanced generations of kodo millet. The important features of these methods are described below.

Methods of hybridization

Natural hybridization

Kodo millet is although a highly self pollinated crop but permit a certain degree of cross pollination nearly 5% in protogynous types (Youngman and Roy, 1923). It results in development of natural hybrids in germplasm.The identification of such natural hybrids in their germplasm would considerably enhance the variability for facility of selection. The intercropping of protogynous genotypes in germplasm/breeding nurseries or in association with selected parents may increase the prospects of natural hybrids.

Artificial hybridization

The methods of emasculation and controlled hybridization have been standardized. Besides this contact method is also being used to enhance cross pollination.

Controlled hybridization: The hand emasculation technique developed by Verma (1989) and modified by Yadava (1997a) has been found effective

in kodo millet. The controlled pollination just after the emasculation helps in development of hybrids.

Contact method of hybridization: The contact method as suggested by Ayyangar and Warian Achuta (1934) for finger millet is being successfully used in kodo millet also with slight modifications. In this method, the panicles of selected plants are tied to other panicle in which crossing is to be attempted before flowering to enhance the chances of natural cross pollination. It resulted in low frequency of true hybrids which can be identified with the help of marker characteristics of the parents in first filial generation.

Selection of transgressive segregates

The recombination breeding is achieving popularity in recent years. The selection of parents to be used in hybridization programme is more important to generate the transgressive variation. This selection should be based on relevant and realistic breeding objectives formulated after a

Table 14. Comparison of mean performance of kodo millet variety JK 76 and protogynous mutant KM 32 for some phenotypic characters

Characters	JK 76 (parent)	KM 32 (protogynous mutant)
Tillers per plant	6.9±0.81	5.8±0.60
Plant height (cm)	35.3±1.69	44.5±2.65
Panicle length (cm)	15.1±0.62	22.2±0.85
Nodes per plant	28.6±2.71	15.9±2.69
Leaves per plant	35.5±3.37	21.8±3.20
Flag leaf length (cm)	27.8±1.67	19.0±0.83
Ear length (cm)	9.5±0.57	7.3±0.31
Days to 50% flowering	55.0±0.94	64.0±0.21
Days to maturity	87.0±0.89	99.0±1.64
Biological yield per plant (g)	28.1±1.64	35.4±2.39
Grain yield per plant (g)	10.4±0.21	7.2±0.25
Growth habit	Erect	Semi-erect
Spikelets arrangement of rachis	2-4 irregular rows	2 regular rows
Plant type	Semi-dwarf	Tall
Panicle emergence	Partial	Complete
Flowering behavior	Cleistogamous	Protogynous
Grain colour	Light brown	Dark brown
Seed shape	Oval	Oval
Shattering	Non-shattering	Shattering

Source: Yadava *et al.* (2003)

sound analysis of farming situations, yield constraints and market opportunity. Considering these factors, the breeding objectives for improvement in kodo millet would be improvement in genetic yield potential with early maturity and grain quality along with resistance to biotic and abiotic stresses. After controlled hybridization between selected parents, the selection for transgressive segregates should be practiced from F_2 or later generations of crosses through conventional breeding methods.

MUTATION BREEDING

The induced mutations may provide an additional source of variation. They have proved a powerful tool to rectify a character or to generate polygenic variation in small millets. The mutants of dwarf stature, profuse

Table 15. Preliminary yield evaluation of mutant lines in kodo millet

Mutants	Tillers/ plant	Plant height	Days to 50% flowering	Days to maturity	Biological yield (tonnes/ ha)	Grain yield (tonnes/ ha)
KM 1	6.9	49.2	57	83	5.63	2.070
KM 3	6.4	49.7	57	91	6.00	2.297
KM 4	7.3	46.1	61	90	5.92	2.445
KM 6	7.0	55.6	59	89	5.53	2.402
KM 7	6.2	56.3	55	91	6.29	2.169
KM 9	6.9	54.4	61	91	5.99	2.499
KM 13	6.6	49.5	63	95	7.14	2.584
KM 17	7.6	54.4	60	94	6.49	2.638
KM 29	6.7	45.1	59	89	4.92	2.578
KM 31	6.9	55.2	61	95	6.81	2.655
KM 40	7.2	57.5	61	96	6.93	2.412
KM 49	6.5	43.7	57	85	5.67	2.377
KM 53	7.0	51.9	57	92	5.90	2.497
KM 74	7.4	52.6	66	90	6.83	2.360
KM 81	6.5	50.6	60	85	6.37	2.537
KM 86	7.1	47.7	62	87	6.96	2.759
KM 87	8.2	57.5	61	92	6.53	2.362
KM 89	6.2	46.2	56	83	6.62	2.157
KM 99	6.6	59.3	60	89	7.19	2.618
KM 100	6.8	55.7	63	95	6.86	2.379
KM 101	7.8	51.9	64	91	7.24	2.598
JK 76 (C)	6.0	57.2	55	85	7.56	2.226
JK 62 (C)	7.0	48.9	57	88	6.44	2.562
RPS 136-1	6.6	57.6	58	91	7.28	2.701

Source: College of Agriculture, Rewa (1997)

tillering, early maturity, long ears and high yield have been developed through induced mutations in small millets (Rao and Goud, 1973; Nayar *et al.*, 1979b; Mehra *et al.*, 1985 and Sarkar *et al.*, 1993). In kodo millet, Mishra *et al.* (1985) was first to induce quantitative variation through gamma irradiation. The varietal sensitivity to gamma irradiation varied from genotype to genotype. Yadava (1997a) found maximum mutation frequency and effectiveness at 25 Kr dose of gamma irradiation. JK 76 was more sensitive to gamma rays as compared to JK 41. The mutants having auricle pigmentation, late maturity, complete panicle emergence and dark brown seed have been developed (Yadava *et al.*, 2003). A protogynous mutant having two rows of spikelets on rachis was also identified from 5 Kr dose of gamma irradiation in JK 76. The distinguish characters of this mutant is mentioned in Table 14. The development of protogynous mutant has opened a new vitas in recombination breeding as it was mostly hampered. Among the mutants identified, KM 86 and KM 99 have high yield potential coupled with early maturity (Table 14 and 15). There is thus ample possibility for improvement following physical and chemical mutagenesis in kodo millet.

MOLECULAR MARKER

Variation in DNA sequence of kodo millet varieties can be detected using recent techniques of molecular genetics. The DNA banding pattern recorded for a particular variety becomes its DNA fingerprint. Since, each variety has unique DNA finger print. Hence, two varieties can be distinguished with the help of this technique. The DNA markers can be broadly classified into two categories:

1. Probe hybridization based markers (RFLP and VNTR)
2. PCR-based markers (RAPD, STMS, ISSR and AFLP)

In kodo millet, M-Ribu and Hilu (1996) studied the molecular markers through RADP (Random Amplified Polymorphic DNA) method and observed a high level of polymorphism in RAPD markers, among individual accessions. They further analysed the RADP markers using cluster analysis, principal co-ordinates and minimum spanning tree method and reported that accessions of north African kodo millet showed higher affinity to Australian types. They suggested that RADP technique can be used to resolve the degree and pattern of genetic variation to identify the cultivars and to define the gene pools in kodo millet.

CHAPTER 4

Crop Production

Kodo millet is well adapted to adverse soil, climate and socio-economic conditions of the farmers. However, the productivity of this crop is though increasing in recent years, but the surface growth rate is very low. The poor growing environment in terms of nutrition, moisture and cultural practices and very slow adoption of improved technology are mainly responsible for slow growth in productivity. There is a good evidence to suggest that a substantial increase in productivity is possible with the adoption of improved technology. Though the cultivation of kodo millet needs very low input but tribal farmers are not able to invest the same. Keeping this in view, the no cost or low cost technologies for higher production have been developed and recommended. The need is to popularize these technologies among the farmers through vigorous extension efforts and demonstrations.

COMPONENTS OF IMPROVED TECHNOLOGY

The improved technology recommended for kodo millet cultivation can be broadly categorize into three components namely no cost, low cost and high cost. The timely operations are no cash or no cost inputs in any farming. The choice of an appropriate variety, timely agricultural operations like tillage, sowing, interculture operations and harvesting are purely no cost production technology. The low cost technology includes the improved seeds, biofertilizers and seed treatments. Seed is the cheapest and most cost effective input in view of the low seed rate. The application of recommended quantity of fertilizers, plant protection measures and chemical weed control are the high cost production technologies.

RECOMMENDED CULTIVATION PRACTICES FOR KODO MILLET

Season

Kodo millet is cultivated mostly in rainy season all over the country. Being a dry land crop, it is normally sown with onset of monsoon from middle of June to end of July. The crop is also sown during July–August in Tamil Nadu.

Weather

As a crop of tropics and subtropics, kodo millet responds favourably to warm weather conditions. The ambient temperature between 20 to 30°C favours the better growth of the crop. Cool conditions are unfavourable. The crop is cultivated in low to high rainfall areas of the country. It is grown near the sea level to high hilly altitude of the central India.

Soil

Kodo millet is adapted to a wide range of the soil types. It grows well in shallow to well drained deep soils. Presently, the crop is mainly cultivated in skeleton gravely and red and laterite soils where fertility status and moisture holding capacity are very low. These soils become hard on drying and form crusts. Hence, occurrence of drought quickly after cessation of rains is a common feature. The crop is also grown in alkaline soil as a fodder crop in Tamil Nadu.

Land preparation

The land preparation for kodo millet cultivation varies from soil to soil. Every year, tillage is highly essential to increase the infiltration and conserve the moisture in skeleton gravely and red and laterite soils. One deep ploughing in summer after summer rains followed by two harrowing with wooden plough is found advantageous before the sowing and also reduces the weed intensity. In rainy season, the ploughing across the slope is necessary to protect the soil from erosion and enhance the soil moisture conservation.

Seed rate and plant density

The optimum plant density for kodo millet is identified as 0.6 million/ hectare (Rao, 1989). It can be achieved by using the seed rate of 10 kg/ha for line sowing and 15 kg/ha for broadcasting (UAS, Bangalore, 1994). The spacing of 22.5 cm between the rows and 7.5 cm within the rows has been found optimum for higher grain yield in Madhya Pradesh. Whereas, the crop requires a spacing of 45.0 cm × 10.0 cm in Tamil Nadu and Karnataka (ICAR, 1987).

Time and method of sowing

Timely sowing is an important and cheapest monitoring input. The crop is generally sown with onset of monsoon. Accordingly, the sowing time extends from middle of June to end of July. Last week of June to 1st week of July is optimum time for sowing of kodo millet in Madhya Pradesh (Dubey *et al.*, 1993 and Jain, 1995). The delayed sowing reduces the grain

yield of late maturing genotypes. The crop responds favourably to dry sowing, 10 days before onset of monsoon in rain assured areas (Hegde and Linge Gowda, 1989 and UAS, Bangalore., 1994). The line sowing gives higher yield as compared to broadcasting due to effective weeding and interculture operations in the crop. Shallow sowing in upper 2-3 cm soil is optimum, because deeper sowing results in patchy germination after rains. It also results in heavy smut incidence in smut susceptible genotypes of kodo millet (Jain, 1995).

Fertilizer and manures

Traditionally, kodo millet is grown in low fertile soils without application of any nutrient inputs. However, experimental results indicate that the crop responds favourably to fertilizer application. The response of kodo millet to nutrients like nitrogen and phosphorus and manures are given here:

Response to nitrogen

Among the major nutrients, nitrogen has the quick and most pronounced effect on vegetative growth and yield of the crop. The first study on response of nitrogen in kodo millet was carried out during 1961 to 1963 at Chhindwara in Madhya Pradesh (Mandloi and Tiwari, 1966). The results indicated that grain yield increased with increase in doses of nitrogen. Similarly, Dubey and Lal (1969) suggested that kodo millet respond up to 30-40 kg N/ha based on their experiments conducted at Rewa. Linge Gowda *et al.* (1977) also recorded significant increase in yield of kodo millet with application of nitrogen and suggested that 25 kg N/ha was remunerative and economical. The increase in levels of nitrogen increased the grain yield of kodo millet significantly up to 60 kg N/ha (Kaushik and Gautam, 1981; Dhagat and Naik, 1982). On other hand, Linge Gowda *et al.* (1986) and Baghel *et al.* (1989) observed gradual reduction in grain yield beyond 40 kg N/ha. Dubey (1991) and Dhagat (1996) also observed linear response of nitrogen up to 20 kg N and 40 kg N/ha. Yadava (1997b) also reported response of nitrogen up to 40 kg N/ha (Fig. 5).

A critical perusal of literature on response of nitrogen indicates that kodo millet though responds favourably to nitrogen application up to 40 kg N/ha or even more in some soils, but the application of 20-25 kg N/ha is remunerative and economical to enhance the grain yield in all the kodo millet growing states of the country except Tamil Nadu. The application of 50% nitrogen as a basal application and remaining 50% as top dressing after first weeding is recommended for getting maximum yields and to reduce the nitrogen losses.

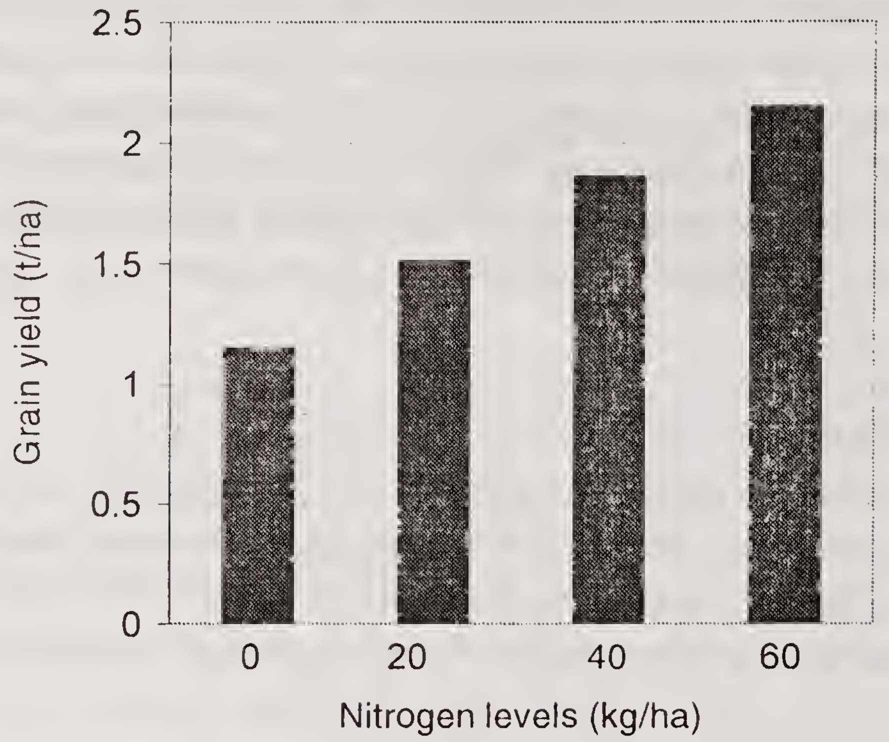

Fig. 5. Effect of nitrogen levels on grain yield of kodo millet
Source: Yadava (1997b)

Response to phosphorus

Phosphorus is one of the major plant nutrients for plant growth. It gives strength and resistance against biotic stresses to the plant. Mandloi and Tiwari (1966) did not found any response of phosphorus in skeleton gravely soils of Madhya Pradesh. However, further studies on this aspect indicated a response of 20 kg P_2O_5/ha (Dhagat, 1996). Kaushik and Gautam (1981), Linge Gowda (1986) and Baghel *et al.* (1989) also emphasize that application of 20 kg P_2O_5/ha increase the grain yield significantly in kodo millet in medium textured soils.

Response to biofertilizers

Biofertilizers are gaining importance because of their low cost as compared to inorganic fertilizers. Hence, attempts have been made to search out effective biofertilizers including P solublizing microorganisms on kodo millet. Vaishya *et al.* (1986) reported that application of *Azospirillum brasilense* inoculants mixed with soil to the furrows or 20 kg N/ha gave grain yields of 0.86 and 0.99 tonne/ha, respectively compared with 0.65 tonne without inoculation or N. Pattanayak *et al.* (1990) and Basak *et al.* (1991) found that partially acidulated rock phosphate (PARP) increased P uptake and grain yield as well as dry forage yield of kodo millet. The inoculation of *Agrobacterium radiobacter* + *Aspergillus awamori* as seed treatment @ 25 g/kg seed (Fig. 6) along with 100% recommended NPK (50% P as super phosphate + 50% P as rock phosphate) resulted in significantly higher grain yield as compared to 100% NPK (Nema, 1994).

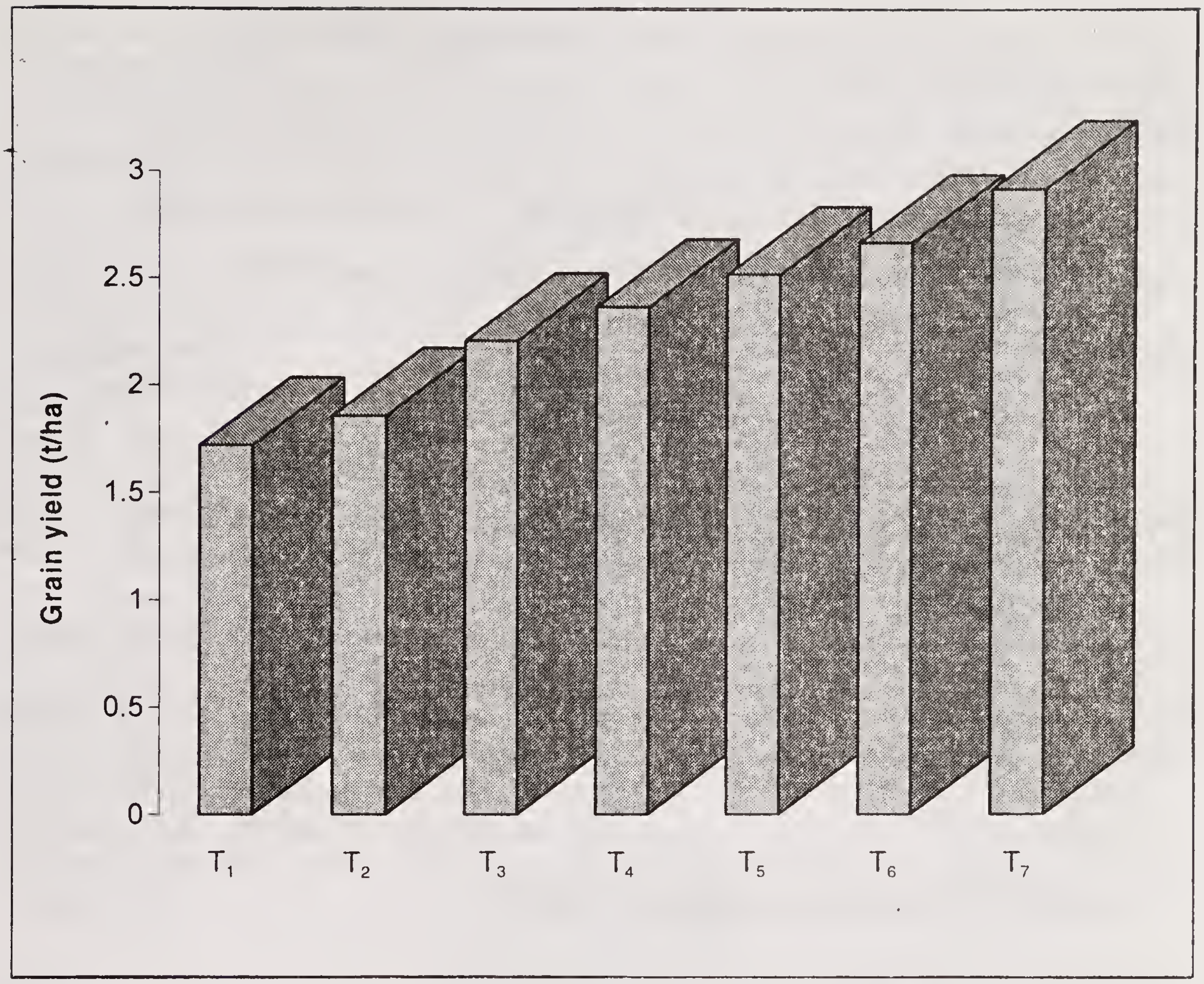

Fig. 6. Effect of biofertilizers on grain yield of kodo millet. T_1, 100% recommended NPK (P as super phosphate); T_2, 100% recommended NPK (50% P as super phosphate + 50% P as rock phosphate); T_3, 100% recommended NPK (P as super phosphate + *Agrobacterium radiobacter* seed inoculation); T_4, 100% recommended NPK (P as super phosphate + *Aspergillus awamori* seed inoculation); T_5, T_2 + *Agrobacterium radiobacter* seed inoculation; T_6, T_2 + *Aspergillus awamori* seed inoculation; and T_7, T_2 + *Agrobacterium radiobacter* + *Aspergillus awamori* seed inoculation

Source: Nema (1994)

Response to manure

The use of Farm Yard Manure (FYM) helps in maintaining the physical property and organic content of the soil. It also increases the absorption capacity of soil for cation and anions particularly nitrates and phosphorus along with moisture holding capacity. Kodo millet responded favourably to application of farmyard manure with an increase in 0.2 tonne gram yield for every 5 tonnes of the manure (Hegde and Linge Gowda, 1989).

Integrated nutrient management

Resource constraints remain always with kodo millet growers, which are the main reasons for negligible/no use of inputs in this crop. The integrated use of fertilizers and manures results significantly higher grain

yield as compared to control. The recommended dose of fertilizers though gave maximum seed yield (Table 16), but the use of FYM alone for recommended level of nitrogen or FYM for 50%recommended N + remaining 50% N through inorganic fertilizers and 75% recommended fertilizers also resulted in significantly higher yield in kodo millet.

Table 16. Effect of integrated nutrient management on yield of kodo millet

Treatments	Grain yield (tonnes/ha)			Straw yield (tonnes/ha)		
	1995	1996	Mean	1995	1996	Mean
FYM for recommended level of N	1.043	1.287	1.165	1.249	1.696	1.472
FYM for 50% recommended N + inorganic fertilizer for 50% N	1.425	1.618	1.521	1.582	2.126	1.854
Recommended fertilizers (40:20:10 kg/ha)	1.794	2.003	1.898	2.048	2.753	2.400
Farmers practice	0.731	0.944	.837	0.998	1.173	1.085
75% recommended fertilizer	1.435	1.669	1.552	1.802	2.525	2.163
SEm±	0.034	0.053	0.043	0.040	0.068	0.055
CD 5%	0.100	0.158	0.128	0.118	0.203	0.161

Source: UAS, Bangalore (1995a and 1996)

Weed management

Weeds are unwanted plants, which compete with crop for soil moisture, macro and micro nutrients, light and space. They also harbour insects and plant pathogens damaging to the main crop. In dry land crop like kodo millet, the competition between weed and crop is largely for water, because the transpiration coefficients of majority of the weeds is higher than cultivated plants. A large number of weeds belonging to different families have been identified from the kodo millet fields (Table 17), although, kodo millet is known as weed reducer (Arjulis, 1990).

Weed seeds are mainly disseminated frequently and widely through wind, water, animals and also human beings. The steps to check the dispersal of weed seed is important to reduce the weeds intensity. The use of pure seeds, summer ploughing, irradiation of weeds from bunds and control of run-off are the important steps to reduce the weed population. Besides this, one hand weeding 20-25 days after sowing (DAS) and one interculture increases the grain yield by 50 to 60% over no weeding in kodo millet (Nema,1994). The results of experiments conducted to know the herbicidal effects in controlling the weeds under AICRP on Small millets (UAS, Bangalore, 1995 and 1996) revealed that two hand weeding at 20

Table 17. Common weeds of kodo millet

Common name	Scientific name	Density status
	Monocot weeds	
Doob	*Cynodon dactylon*	High
Sawan	*Echinochloa crus-galli*	High
Baru grass	*Sorghum halepense*	Low
Montha	*Cyperus rotundus*	High
Banari	*Setaria glauca*	Low
Kans	*Saccharum spontaneum*	Medium
	Dicot weeds	
Chhoti dudhi	*Euphorbia hirta*	Medium
Badi dudhi	*Euphorbia prostrata*	Medium
Mahakama	*Ageratum conyzoides*	Medium
Hazardana	*Phyllanthus niruri*	Medium
Satyanasi	*Argemone mexicana*	Medium
Chirchita	*Achyranthes aspera*	Low
Murga	*Celosia argentea*	Low
Ghamira	*Eclipta alba*	Medium
Phulani	*Tridax procumbens*	Low
Adhisishi	*Xanthium strumarium*	Medium
Katili chauli	*Amaranthus spinosus*	Medium
Jungle jute	*Corchorus acutangulus*	Low
	Semi parasitic weeds	
Agiya	*Striga densiflora*	Medium
Agiya	*Striga asiatica*	Low

and 40 days after sowing followed by twice interculture at 20 and 40 days after sowing and one hand weeding at 20 DAS gives higher yield (Table 18) but the application of Isoproturon @ 0.50 kg ai/ha as pre-emergence or 2,4,D Na salt @ 0.75 kg ai/ha post emergence after 20 DAS resulted significantly higher grain yield in comparison to control (no weeding).

Intercropping

Intercropping reduces the risk of uncertainty in substantial rainfed farming. Kodo millet being a rainfed crop is grown predominantly in hilly tracts either as a sole crop or mixed crop with sesamum, niger, pigeon pea and sorghum. Raghu and Choubey (1982) and Tiwari *et al.* (1994) suggested that intercropping of kodo millet, little millet and barnyard millet are more remunerative than the growing these crops as a sole crop. Hegde and Linge Gowda (1989) also emphasize for identification of an acceptable intercropping system in kodo millet. The studies conducted on intercropping of kodo millet with different pulse and oilseed crops in

Table 18. Effect of weed management on yield of kodo millet

Treatments	Grain yield (tonnes/ha)			Straw yield (tonnes/ha)		
	1995	1996	Mean	1995	1996	Mean
2, 4-D Na salt @ 0.40 kg ai/ha as post-emergence at 20 DAS	0.679	1.214	.946	1.158	1.852	1.505
2, 4-D Na salt @ 0.75 kg ai/ha as post-emergence at 20 DAS	0.800	1.373	1.086	1.213	2.146	1.679
Isoproturon @ 0.25 kg ai/ha as pre-emergence	0.596	1.324	.960	1.028	2.235	1.631
Isoproturon @ 0.50 kg ai/ha as pre-emergence	0.706	1.451	1.078	1.130	2.508	1.819
One hand weeding at 20 DAS	1.158	1.337	1.247	1.519	2.053	1.786
Two hand weeding at 20 and 40 DAS	1.728	1.972	1.850	2.158	2.678	2.418
Inter-cultivation twice at 20 and 40 DAS	1.296	1.643	1.469	1.958	2.043	2.000
Control (no weeding)	0.349	0.669	0.509	0.500	1.071	0.785
SEm±	0.080	0.103	0.091	0.077	0.158	0.117
CD 5%	0.239	0.308	0.272	0.234	0.461	0.348

Source: UAS, Bangalore (1995 and 1996)

Madhya Pradesh revealed that intercropping of kodo millet with pigeon pea in 2: 1 ratio is economical for higher yield, net return and income per rupee invested in medium textured soils (Baghel *et al.* 1989 and 1991, Bajpai and Singh, 1992). A combination of kodo millet with groundnut in the row ratio of 1: 1 followed by 2: 1 was better than single crop in groundnut growing areas (Hegde and Linge Gowda, 1989). The recent studies of intercropping of kodo millet in skeleton gravely soils (Table 19) also revealed that intercropping of kodo millet with pigeon pea in 2: 1 row ratio followed by 1: 1 ratio results in highest kodo equivalent yield, maximum return and income per rupee invest.

Crop rotation

Kodo millet gives potential yield in the areas where other crops have less chance of adaptation. It is the reason that monocropping is prevalent in most of the kodo millet growing areas. Shifting cultivation is also vogue in hilly tracts of major growing states of this crop. In Madhya Pradesh, kodo millet is grown for two years followed by one year of niger and then giving a rest for one year in gravelly skeleton soils, which are predominant in hill agriculture.

Table 19. Intercropping studies in kodo millet under rainfed conditions

Treatments	Grain yield (tonnes/ha)				
	Main crop	Companion crop	Kodo millet equivalent grain yield	Net return (Rs/ha)	Income per rupee invest
Kodo millet pure crop	2.196	-	2.196	4,523	1.46
Pigeonpea pure crop	-	0.544	2.588	3,882	1.46
Greengram pure crop	-	0.405	1.507	1,141	0.77
Blackgram pure crop	-	0.594	2.219	3,588	1.36
Kodo + pigeonpea (1:1)	1.217	0.361	2.940	5,416	1.63
Kodo + pigeonpea (2:1)	1.678	0.285	3.036	6,134	1.91
Kodo + pigeonpea (6:1)	1.900	0.148	2.597	4,719	1.60
Kodo + greengram (1:1)	1.250	0.229	2.151	3,218	1.23
Kodo + greengram (2:1)	1.602	0.125	2.171	3,306	1.27
Kodo + blackgram (1:1)	1.343	0.534	2.670	5,211	1.68
Kodo + blackgram (2:1)	1.675	0.224	2.502	4,543	1.55
Kodo + blackgram (6:1)	1.900	0.128	2.372	4,161	1.48

Data are based on average of 1995 and 1996; Economic parameters are based on prevailing market price.

Source: UAS, Bangalore (1995, 1996)

The cropping sequence in kodo millet based farming situations under different ecological zones of Madhya Pradesh is presented in Table 20. It alarms the need to identify the research towards developing the kodo millet based double cropping system. The early maturing and high yielding varieties of kodo millet, recommended for cultivation in recent years can fit well in identifying the kodo millet based cropping system.

Harvesting, threshing and storage

The traditional methods of harvesting and threshing are in practice in kodo millet. The whole plant is cut at the base by traditional sickles at maturity. Over mature harvesting is also in vogue due to non shattering nature of panicles. After harvesting, crop is brought to the threshing floor. The threshing is done either by beating with the sticks or by trampling. The produce is then dried in the sun and winnowed. The seed moisture content of 9 to 13% is optimum for storage. The grains can be stored for many years without damage by store pests even under ordinary storage conditions. Generally the grains are stored in gunny bags, earthen bins (kothi) and portable bins (Bhakra) rarely the metallic bins are also used for storage. The grains can also be stored in Hapur bins, RCC bins and Pusa bins.

Table 20. Cropping systems on kodo millet based farming situations in different agro-ecological zones of Madhya Pradesh

Zones / farming situations	Characteristics of farming situation			Cropping sequence
	Soil	Rainfall (mm)	Elevation (m.a.s.l.)	
1	2	3	4	5
	North hill region of Chhattisgarh			
Hilly terrains, rainfed	Skeleton gravelly	1400-1600	916-1372	Kodo millet – fallow Little millet – fallow
Slopy uplands, rainfed	Gravelly	1200-1600	617-915	Niger/sesame – fallow As in hilly terrains
Unbunded uplands, rainfed	Sandy to sandy loam	1200-1600	617-915	Finger millet - fallow Kodo + red gram + blackgram Little millet - fallow
Uplands rainfed (a) Fields (b) Baries	Sandy loam	1200-1600	306-616	Kodo millet – fallow Kodo millet + redgram Rice – fallow, Maize – *toria* Maize + *Jowar* + vegetables
	Baster plateau			
Hilly terrains, rainfed	Entisols (Marhani)	1400-1600	615-1050	Kodo millet – fallow Little millet – fallow Barnyard millet – fallow Finger millet – fallow, Little millet – kosra
Slopy uplands, rainfed	Entisols (Tikra)	1400-1600	615-915	As in hilly terrains Little millet – *kulthi*
Unbunded uplands	Inceptisols/ alfisols (Mar)	1400-1600	306-614	As in sloppy uplands Little millet/ finger millet - *kosra*

(Table 20 *continued*)

(Table 20 *concluded*)

1	2	3	4	5
		Kymore plateau and Satpura hills		
Sandy to sandy	Inceptisols (Segon/Domat)	1000-1200	616-975	Kodo millet – fallow Kodo millet + jowar + redgram Kodo + red gram + blackgram
Sandy clay loam, loam	Inceptisols	1000-1200	306-615	As in sandy to sandy loam
Sandy loam, rainfed	Alfisols	850-1200	306-615	Rice – fallow Kodo millet based mixed cropping Rice - fallow
		Satpura plateau		
Hilly terrains, rainfed	Entisols (Gravelly)	1000-1200	615-915	Small millets fallow, kodo millet + redgram kodo millet + redgram + jowar
Hilly slopes, rainfed	Entisols Inceptisols	1000-1200	615-915	As in hilly terrains
Unbunded uplands, rainfed		1000-1200	306-615	As in hilly slopes
Chhatisgarh plains				
Unbunded upland Bhatu soil, rainfed	Entisols (Gravelly)	1200-1500	615-915	Kodo millet – fallow Sesamum – fallow
Unbubded upland, Tikra soil, rainfed	Entisols	1000-1200	305-615	Small millets – fallow Kodo millet + redgram
Unbunded upland, Gosra, Kanhar soils	Alfisols/ Vertisols	1000-1200	153-305	Small millets – fallow Kodo + *jowar* + redgram + blackgram
		Other zones		
Sandy to sandy loam, rainfed	Inceptisols	600-800	305-915	Millets – fallow kodo millet + *jowar* + redgram
Sandy clay loam soil,rainfed	Inceptisols	800-1200	305-615	As above
Sandy loam soils, rainfed	Inceptisols/Alfisols	800-1200	153-305	As above

CHAPTER 5

Crop Protection

Kodo millet suffers due to attack of diseases and insect pests, which causes enormous losses in grain yield. Host and favourable environmental conditions influence considerably the severity of diseases and pests. The evolution of new high yielding varieties may encourage the build up of disease and pests, which were not predominant before. The major diseases and pests, nature of damage, etiology of causal agent and their effective control measures are summarized below.

DISEASES

A number of diseases are reported to occur in kodo millet. These diseases along with their causal organism, nature and status of occurrence are presented in Table 21.

Table 21. Diseases of kodo millet in India

Disease	Causal organism	Nature	Status
Fungal			
Head smut	*Sorosporium paspali thunbergii* (P.Henn.) S. Ito	Seed borne	Major
Ergot	*Claviceps paspali* Stev. & Hall	Soil and air borne	Minor
Rust	*Puccinia substriata* Ellis & Barth.	Air borne	Minor
Leaf blight	*Alternaria alternata* (Fr.) Kiessler	Air borne	Minor
Udabatta	*Ephelis oryzae* Syd.	Soil borne	Minor
Leaf spot	*Helminthosporium holmi* Luttrell	Unknown	Minor
Matona	*Phomopsis paspali, Aspergillus flavus*	Unknown	Minor
Bacterial			
Bacterial leaf streak	*Xanthomonas* sp.	Unknown	Traces
Bacterial leaf blight	*Xanthomonas oryzae*	Unknown	Traces
Phanerogamic parasite (Witch weed)	*Striga densiflora* *Striga asiatica*	Semi root parasite	Minor

Head smut [*Sorosporium paspali thunbergii* (P. Henn.) S. Ito]

Distribution

Head smut of kodo millet was first reported from Queensland, Australia and was named as *Sorosporium paspali* McAlp (McAlpine, 1910). The smut recorded in east Asia was first described as *Ustilago paspali thunbergii* Henn. Ito (1935) renamed it as *Sorosporium paspali thunbergii* (P.Henn.) S. Ito. The same name of this smut was adopted by Fisher (1953) and it was universally accepted. Later on, disease was reported from India by Butler (1918) and China by Teng (1947).

In India, Butler (1918) recorded it from Chamta ghat and Monghyer, Thirumalachar and Mishra (1953) from Bihar, Mundkar and Thirumalachar (1952) from Bellur near Mysore, Mishra *et al.* (1976), Jain and Verma (1989) from Jabalpur and Rewa in Madhya Pradesh. The disease was also reported from Karnataka, Andhra Pradesh and Tamil Nadu (Pall *et al.*, 1980, Viswanath and Seetharam, 1989). At present, the disease is endemic in all the states of the country. The severity of disease has been reported from 0.0 to 56.4% depending upon the soil, climate and host (Jain and Verma, 1989; Jain *et al.*,1993; Jain and Gupta, 1993a; Mantur *et al.*, 1988).

Fig. 7. Head smut of kodo millet
Source: All India Co-ordinated Research Project on Small Millets, Rewa (Madhya Pradesh)

Symptoms

Typical symptoms are visible as the crop approaches to flowering. The entire affected panicle is transformed into a long sorus, which is 5 to 7.5 cm long and about 0.6 cm broad (Fig. 7). The entire sorus remain surrounded with a creamy membrane in early stage. Sometimes the sorus remains enclosed in the boot leaf and does not emerge fully. The sorus destroys whole inflorescence and exposes black masses of spores when sorus membrane bursts. Necrotic streaks on boot leaf covering infected panicle also develop some times.

Pathogen

Spores of the fungus known as teliospores are borne in loose spore ball like masses of 60 µ × 30 µ in diameter. Spore ball disintegrate into individual spores after applying little pressure. The individual spores are globose, angular to roughly peared shaped, dark to yellowish brown with thick smooth wall of 11- 18 µ × 8-12 µ in diameter. The spore germinates by producing septate, single or branched hyphae constricted at septum, which bears lateral and terminal sporidia.

Etiology

The maximum temperature for germination of *S. paspali thunbergii* teliospores was from 24.5 to 37.5°C, while minimum was below 19°C. The optimum temperature for spore germination was 30°C (McRae, 1928 and 1930). Ahmed (1991) also recorded maximum growth of fungus at 30°C and reported *p*H 4.1 to be the best for growth. However, fungus can grow on alkaline medium from *p*H 7.1 to 8.1 also.

The fungus prefers organic forms of nitrogen rather than inorganic forms.The radial growth of *S. paspali thunbergii* was recorded by Ahmed (1991) on eight culture media. Maximum radial growth of fungus was on Potato Dextrose Agar (PDA) followed by Czapek's Agar and Paspalum grain meal agar medium. Colour of the culture ranged from buff or vinaceous buff to whitish or hazel. The consistency of the culture was leathery on different medium. The margin was smooth or fimbriate or wavy. Dull lusture was recorded in all the tested media except in Echinochloa grain meal agar, on which it was shiny. Large variation in surface and topography of the culture was recorded. On media like PDA, potato sucrose agar, potato sucrose malt extract agar, Czapak's agar and richard's agar, the mycelial growth was maximum on day 18 after inoculation (Ahmed, 1991).

The nutritional requirement of *S. paspali thunbergii* has been studied by Ahmed (1991). It utilize monosaccharides efficiently followed by polysaccharides but preferred polysaccharides the least. The fungus

preferred organic form of nitrogen over inorganic form. Glutamic acid was the best source of nitrogen, while urea was poorest source for *S. paspali thunbergii.*

Disease cycle

The disease is seed borne in nature. The smut spore balls remain adhered on the seed surface as seed contaminant (McRae, 1930; Mundkar, 1945 and Sattar, 1930). The seed contamination results into systemic infection. Sattar (1930) recorded infection from crop residue in soil. However, the infection was subjected to rains before sowing of the crop. Later, Ramakrishnan (1963) described it as soil borne disease also, which was confirmed by Ahmed (1991). Jain and Gupta (1993a) also found infection through soil infestation but the disease incidence was very low. The soil borne inoculums also leads to systemic infection (Jain and Khare, 1999). It could be, therefore, concluded that head smut of kodo millet is both seed and soil borne. Seedling infection occurs by penetration of germ tube through cell wall. The resulting mycelium develops both inter and intra cellularly in host tissues (Sattar, 1930 and Ahmed, 1991). The mycelium become systemic and enters the meristematic tissues, which finally infect the ear head (RamaKrishnan, 1963). Teliospore formation by the fungus progress from pith towards epidermis. No sign of hypertrophy or hyperplasia of infected cells was observed. Hyphae get established in all the infected tissues except xylem vessels (Ahmed, 1991).

Inoculation techniques

A suitable method is essential for screening of genotypes against *S. paspali thunbergii* under artificial epiphytotics because uniform infection does not occur under natural conditions. Seedling inoculation with viable sporidial suspension results in maximum incidence (Ahmed, 1991). Jain and Gupta (1993a) observed that mixing of seed with viable teliospores @ 2 g/kg seed before sowing was the best for creating artificial epiphytotics of the disease. Our recent studies at Rewa further indicate that the spore load @ 3 g/kg seed is significantly better in comparison to 2 g/kg seed. The soil inoculation results comparatively poor in disease incidence. Though the technique of Ahmed (1991) for artificial inoculation is better but it has certain limitations under field conditions. Hence, the method developed by Jain and Gupta (1993a) with slight modification of 3 g teliospore/kg seed can be adopted as an efficient technique for artificial inoculation in kodo millet (Jain, 2000).

Host range

Knowledge about host range of pathogen is important for its survival.

Ahmed (1991) tried other small millets as collateral host of *S. paspali thunbergii* but the fungus failed to survive on *Eleusine coracana, Setaria italica, Panicum miliaceum, Panicum sumatrense* (*P. miliare*), *Echinochloa frumentacea* and *E. colonum.*

Yield losses

As the entire panicle is converted into smut sori, hence, studies on yield losses is very limited. Jain and Yadava (1997) recorded considerable yield losses ranging from 13.15 to 32.98% at the disease pressure of 13.15–40.15% but the loses varies according to disease intensity and host.

Disease management

The disease can be managed by adopting the resistant varieties, optimum cultural practices and cheaper fungicides. Jain and Khare (1999) reviewed the management practices to minimize the smut incidence.

Table 22. Sources of resistance to head smut identified in kodo millet

Cultivars / germplasm	Reference
KMV 8, KMV 20 and RPS 136-1	Rao *et al.* (1988)
KMV 20 and RPS 136-1	Viswanath (1992)
TGBKK 1, 3, 5, 6, 7, 8, 9, KMV 8, KMV 20 and D 73	Dantre and Rao (1993)
JK 41, JNK 117 and KMV 8	Jain and Gupta (1993a)
GPLM 717, 779 and 788	Jain *et al.* (1993a)
DPS 34, DPS 77 and DPS 104	Jain (1995)
JK 41, JK 62, JNK 117, KMV 8, ICK 6902, GPLP 3, GPLP 41 and GPLP 54	Jain *et al.* (1997)

Varietal resistance: The sources of resistance are important for their direct use if present with high yield or use in breeding programme for developing high yielding varieties. Some genotypes exhibited resistance against *S. paspali thunbergii* on artificial screening of available cultivars/germplasm (Jain *et al.*, 1997). It is fortunate that recently recommended varieties of kodo millet namely JK 41, JK 62, KMV 20 and RPS 136-1 possessed resistance against head smut. Besides, some sources of resistance/ moderately resistance to head smut pathogen have been identified by various workers in the country which are mentioned in Table 22. These genotypes could be used as a donor for resistance against smut of kodo millet.

Cultural control: Field sanitation by destroying infected plants and burning their straw reduces the primary inoculums. Verma (1989) reported

that the intensity of the disease was more in black soil as compared to red gravel and red soils. Early sowing though suffers with slight higher incidence but gives higher yield (Jain, 1995). The delayed sowing reduces the incidence with low yield (Viswanath, 1992 and Jain, 1995). The deeper sowing (5-10 cm) and delayed emergence of coleoptile from soil provide more chance for infection by the fungus. Shallow sowing is helpful in early emergence and results in less incidence of head smut (Jain, 1995). The increase in nitrogen level increases the head smut incidence. The balance application of NPK fertilizers is desirable to minimize the head smut incidence in kodo millet.

Chemical control: Sattar (1930) observed that steeping of kodo millet seeds in 1.5% copper sulphate solution or treatment with copper carbonate @ 6.24 g/kg of seed reduce the incidence of head smut by nearly 50%. Ahmed *et al.* (1994) reported that *in vitro* carboxin, carbendazim, emisan and thirum at 500 ppm gave complete inhibition of *S. paspali thunbergii. In vivo*, the seed treatment with fungicides such as carboxin, carbendazim, dithane M-45 and parasan have been found effective against head smut (Parambaramani *et al.* 1973; Pall, 1985; Chalam *et al.* 1989; Jain and Gupta, 1993b and Jain, 1995). The recent studies conducted with new fungicides at Rewa indicated that seed treatment with chlorothalonil, carbendazim, emisan @ 2 g/kg seed and raxil @ 1.5 g/kg seed were most effective in reducing the disease with higher yield (Jain, 1999). Mantur *et al.* (1997) reported that chlorothalonil followed by emisan (2g kg seed) gave the best control of head smut at Bangalore.

Ergot (*Claviceps paspali* Stev. & Hall)

Distribution

The occurrence of ergot or sugary disease on *Paspalum dilatatum* was first reported from America (Stevens and Hall, 1910) and further from Burma (Butler and Bisby, 1931). Later on, the disease was recorded from Kodaikanal (Tamil Nadu) and Assam in India (Ramakrishnan and Sundaram, 1950) and Italy (Grasso, 1952). The pathogen (*Claviceps paspali* Stev. and Hall) is widely distributed throughout the world on other species of *Paspalum*, specially used for forage like *P. dilatatum*. The disease is of minor importance in the country.

Symptoms

The conspicuous symptoms are visible only after the emergence of panicle. The disease affects the individual spike, but sometimes most of the spikes of a panicle remains affected. The disease becomes evident as small droplets of light honey coloured fluid (honey-dew) which ooze out

of the infected spikes. The ooze may overflow over the lemma and palea and harden into reddish brown crust. A plectenchymatous mass of fungal growth replaces the ovary. Dark grey sclerotia are formed in affected spikes at maturity.

Pathogen

A large number of conidia are found in the honey dew. They are formed from the tip of closely arranged conidiophores produced on the mycelium of fungus. Conidia are hyaline, oblong and granular or guttulate. The size of conidia ranged from 9–18 µ × 3-6 µ with a mean of 15 × 5 µ. Conidia germinates within 3 hr by producing germ tube which bears secondary conidia on tips. Secondary conidia are smaller in size comprising average size of 8 × 4µ ranging from 6-12 µ × 3-6 µ. The sclerotia are dark, oblong and measure 1.5-2.3 mm × 1.2 mm. Sclerotia projects out between the lemma and palea. The sclerotial germination on *P. scrobiculatum* has not been observed but developmental stages of the strains are reported on other species of *Paspalum*. A number of pin head like stromatoid structures bearing numerous sunken perithecia in the terminal swollen portion are produced on germination from each sclerotia. The asci produced in perithecia, which are hyaline, cylindric clavate with average size of 130 µ × 3.3 µ. The asci contains eight ascospores, which are hyaline and slender with average size of 101 µ × 0.75 µ.

Disease cycle

The disease is air borne. The conidia or ascospores infects the spike at early stage. Sclerotia contains alkaloids which are not harmful to consumers, but it may cause paralysis or sometimes death in cattles.

Disease management

Ergot or sugary disease may be controlled by use of clean seed, long crop rotation with non cereal crop and repeated summer ploughing. Infected plants must be uprooted and destroyed before they produce sclerotia. Seed lots containing sclerotia can be separated by immersing them in 20% solution of commercial salt.

Rust (*Puccinia substriata* Ellis & Barth.)

Distribution

Rust of kodo millet was first recorded in India from Himalayan hills at Kanaighat (Sylhet) in east and Kumaon hills, and it was named as *Uredo paspali scrobiculati* Syd. Afterwards the fungus was recorded from Coimbatore in India and Ceylon. It was renamed as *Puccinia substriata*

Ellis & Barth. (Ramakrishnan and Sundaram, 1954) after recording its both uredial and telial stages. Cummins (1942) recorded *P. substriata* on *Paspalum setaceum* in USA.

Symptoms

The symptoms are visible on upper surface of leaf blade and leaf sheath after formation of oval, erumpent and brown uredia. The dark brown telia are usually formed on the lower surface of leaf blade. They remain covered under the epidermis for a long time. The fungus remain present throughout the year on alternate hosts like grasses.

Pathogen

The uredospores measuring an average size of 31 m × 25 m are subglobose to elliptical, light brown and finely echinulate. They germinate readily in water drops within 3 hours and produces one or more stouted germ tube. The incubation period is 8-12 days. Four equatorial germ pores are present in uredospore. Teliospores are two celled, oblong, rounded at both ends with smooth uniform thick wall and size of 40 m × 22 m ranging from 28-47 m × 19-28 m. The pedicels are coloured and short. Paraphyses are present in both uredia and telia.

Disease Management

Incidence of rust may be controlled by the use of resistant varieties. Foliar spray of Zineb (0.25%) is also found effective in controlling the disease.

Matona disease

The grain and straw of kodo millet infected with a whitish fungus produces unconsciousness, vomiting, giddiness in humans and cattle's after their use as food. It is known as Matona in north India and Kiruku varagu in south India.

Symptoms

The affected plant parts like leaf, panicle, stem and grains show whitish fungal growth during reproductive stage of the crop. Initially small patches of fungus are seen which grow very fast in humid environment or just after the rains. As a result whitish mycelium can be seen in most part of the plants and grains. Bhide and Aimen (1959) suggested that glumes, lemma and palea contained poisonous alkaloids but it has not been observed in any cases.

Pathogen

The Matona is suppose to caused by fungal species. *Phomopsis paspali* was isolated from the affected ear heads and grains. The fungal culture contains the toxin paspalin P I and paspalin P II (Pendse, 1974 and Deshmukh *et al.*, 1975). Ansari and Shrivastava (1991) reported that a toxigenic strain of *Aspergillus flavus* was also associated with the seeds and produces Afla toxin B1. These toxins may be responsible for Matona disease of kodo millet. However, it needs extensive studies on causal agent, metabolites produced by them and their control measures.

Disease management

Destruction and burning of infected plants at the time of harvesting results in elimination of Matona. The fungus spreads rapidly in humid environment. Hence, harvested heaps should be protected from the rains. Similarly, the traditional practice of threshing particularly in Madhya Pradesh by moistening the plants before threshing should be avoided and only dried plants should be threshed. The winnowing of infected seeds also helps in reducing the spread of disease.

Phanerogamic parasite (*Striga* spp)

The partial semi root phanerogamic plant parasite (*Striga* spp.) is found associated with the root of kodo millet (Kumar, 1940; Bharathalaxmi, 1983; Reddy and Dastagiraiha, 1987; Jain and Tripathi, 2002). These weed parasites are reported from all the kodo millet growing areas of the country. With the predominance of *Striga asiatica* L. Kuntze and *S. densiflora* Benth., sorghum, pearl millet, maize, finger millet and barnyard millet are the other host.

Symptoms

Striga species causes stunting and weakening of the host plant. The infestation becomes visible only after its emergence from the soil. The roots of parasite form haustoria, which penetrate the host root for absorption of water and nutrient.

Yield losses

The loss in grain yield per plant was from 42.4 to 65.8%. Similarly, reduction in yield attributes was varied from 6.6 to 13.7% for 1,000 grain weight, 9.5 to 18.9% for plant height, 4.8 to 32.8% for tillers per plant, 5.9 to 27.3% for panicles per plant and 2.8 to 11.9% for length of panicles (Jain and Tripathi, 2002).

Disease management

The weeding of *Striga* species before flowering is the best effective

method for its eradication. Application of nitrogenous fertilizers also reduces the intensity of *Striga* (Bharathalaxmi, 1983). Adoption of legumes in crop rotation also reduces the spread of Striga. Kodo millet varieties JK 41 was found least infected by *Striga* (Jain and Tripathi, 2002).

INSECT-PESTS

The occurrence of insect-pests in kodo millet is very low. Among the insect pests of kodo millet, shoot fly causes considerable losses. Rest of the insect-pests are of minor importance in this crop. Kodo millet is only the cereal crop, which remains absolutely free from store grain pests during storage. The list of insect pests damaging the plant of kodo millet are presented in Table 23 along with their damaging stage and status of occurrence.

Table 23. Insect-pests of kodo millet in India

Common name	Scientific name	Damaging stage	Affected plant parts	Status
Shoot fly	*Atherigona* spp	Maggot	Growing point	Major
Gall midge	*Orseolia* sp.	Maggot	Spikelet	Minor
Stem or pink borer	*Sesamia inferens*	Caterpillar	Stem	Minor
Leaf roller	*Marasmia trapezalis*	Caterpillar	Leaf	Minor
Jassid	*Hecalus* sp.	Nymph and Adult	Leaf	Minor
Gundhi bug	*Leptocorisa acuta*	Nymph and Adult	Leaf	Minor
Army worm	*Mythimna separata*	Caterpillar	Leaf	Minor
Grass hopper	*Acrida exaltata*	Nymph and Adult	Leaf	Minor

Shoot fly (*Atherigona* spp)

Distribution

Jotwani *et al.* (1969) enlisted shoot fly species infecting the kodo millet and other minor cereals at Delhi. Pradhan (1971) reported *Atherigona bituberculata* as kodo shoot fly. Raja Guruswamy and Natrajan (1974) reported the occurrence of shoot fly as a pest of *Paspalum* from south India. Nayar *et al.* (1979a) enlisted 3 species of shoot fly namely *Atherigona simplex, A. oryzae* and *A. pulla*. The attack of shoot fly on *Paspalum* in Madhya Pradesh was reported by Katiyar *et al.* (1981). Singh (1984) recorded *Atherigona miliaceae* as *Paspalum* shoot fly (Fig. 8). Presently the 5 species have been thus reported so far attacking kodo millet in India. They

are *Atherigona simplex, A. miliaceae, A. pulla, A. bituberculata* and *A. oryzae*.

Nature of damage

Shoot fly is a seedling pest, which attack the plant at seedling/tillering stage from 3-5 weeks after sowing. The shoot fly also remain associated with older plants, but damage is very less. The infected plant showed "dead hearts" caused by the tiny maggots, when entered in central shoot. More tillers are produced when main tiller is damaged by shoot fly. Maximum population of shoot fly are observed from last week of July to first fortnight of August.

Economic losses

Patel and Rawat (1982) recorded 49% yield losses in kodo millet due to attack of shoot fly. Nagesh Chandra and Musthak Ali (1983) reported 35% reduction in yield due to attack of shoot fly in kodo millet.

Life cycle

The total life cycle of *Atherigona simplex* from egg to adult (Fig. 8) completed in 19 days (Singh, 1984). The adults were observed to live from

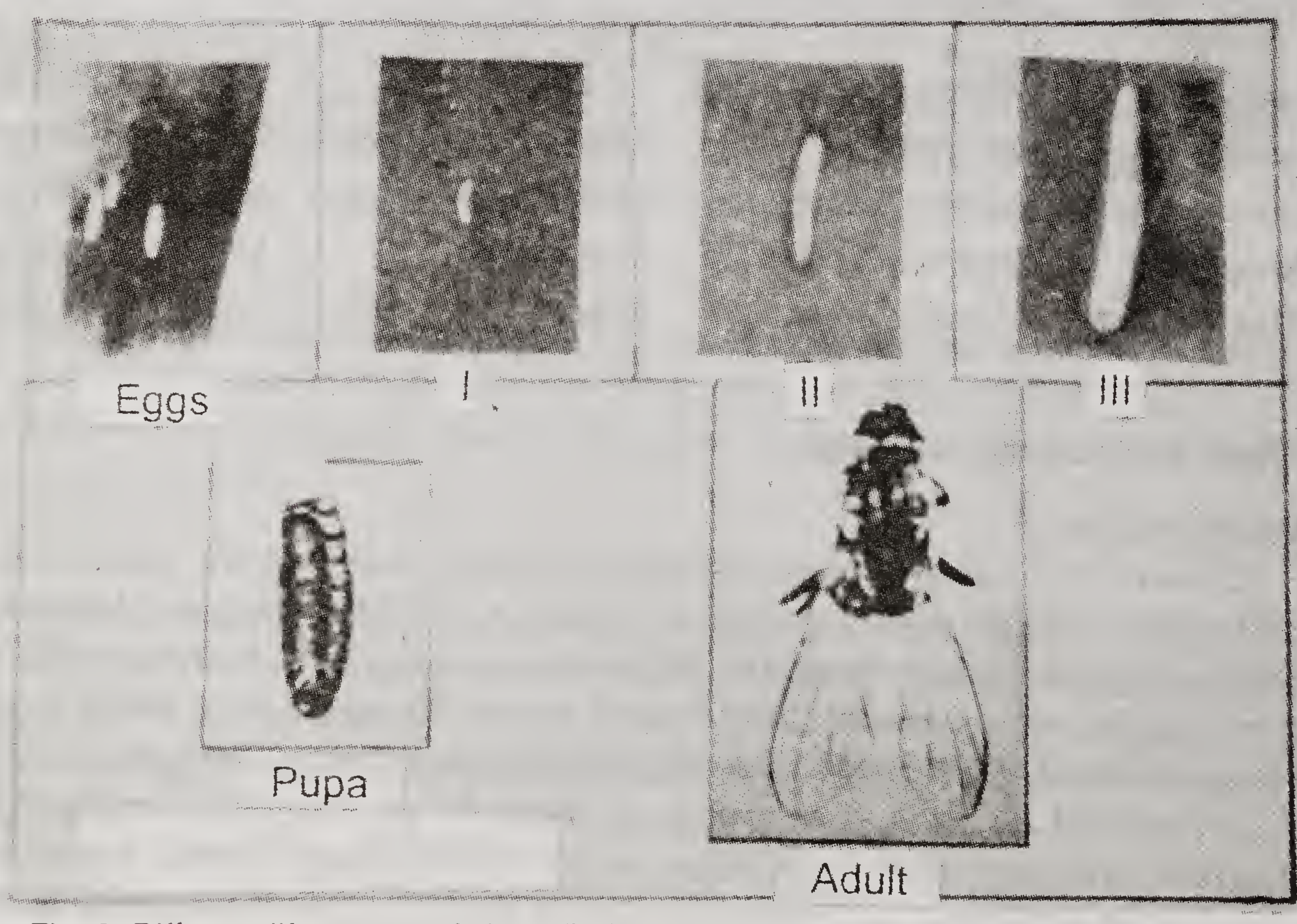

Fig. 8. Different life stages of shoot fly (*Atherigona miliaceae*)
Source: Singh (1984)

1-8 days. The adults generally laid the eggs in morning (8-9 AM) or in evening just before sunset. The eggs were laid singly but sometimes in 1 or 2 rows having 2-3 eggs in each row. The fecundity varied from 10-15 eggs/female during the life span of 3-4 days. Freshly laid eggs are white coloured, sculptured, elongated and remain deposited inside the leaf mostly on stem base. The eggs are cylindrical in shape and tapered at both ends measuring a size of 1.2 mm × 0.35 mm. The incubation period lasts for 1–2 days. The anterior end become darker before hatching and larva comes out in about 2–3 minutes from cell after rupturing the tip.

Newly hatched maggot rest for half an hour near the egg shell, then migrate to upper surface of the leaf blade and moves along the leaf margin towards the leaf sheath. It moves down between leaf sheath and axis of stem and enters into the stem at base by puncturing from lateral sides. Finally maggots cut the growing point of shoot and destroyed it centrally by feeding on the tissues. It thereby causes the characteristic "dead heart". The larvae undergo two moultings and larval period lasts within 7–9 days. Larva converts into pupa within 6-8 days. The pupation takes place inside the stem at the base. Sometimes, it also occurred on lower surface of stem or in soil surrounded by stem. Only one pupa is formed inside one seedling and changes its colour from light brown to deep brown. The puparium is barrel shaped with 4.75 mm × 1.00 mm in size. Pupa contains 10 visible segments with pupal period of 8–10 days.

Freshly emerged adult is dirty grey with a length of 4.5–5.0 mm. Males are smaller than females. The females having a dark marking on the posterior end of the abdomen, which differentiate it from male.

Disease management

Varietal resistance: Development of resistant variety is the best and cheapest way for controlling any insect-pest. The varieties developed and recommended for cultivation in recent past possess good resistance against shoot fly. These are Jk 41, Jk 62, GPUK 3, RPS 136-1 and KMV 20 (Singh *et al.*, 1990 and 1993). Among them GPUK 3 possessed stable resistance for shoot fly, while KMV 20 and RPS 136-1 exhibited the resistance against shoot fly under good management conditions (Singh *et al.*, 1997). The genotypes showing relative resistance to shoot fly are summarized in Table 24. These genotypes should be utilized in breeding programme aiming to develop high yielding lines with resistance to shoot fly in kodo millet.

Cultural management: Early sowing with onset of monsoon or in second fortnight of June resulted in low infestation of shoot fly as compared to late sowing (Murthy and Harinarayana, 1989; Singh *et al.*, 1984 and 1993). The early sowing also resulted in higher yield.

Table 24. Sources of resistance against shoot fly in kodo millet

Resistant sources	Reference
RPS 123, RPS 75-2, RPS 69-2, RPD 1-1 and Keharpur	Singh (1984)
RPS 117 and RPS 40-1	Singh *et al.* (1984)
GPLM 6, 11,20, 21, 29, 32, 39, 42, 45, 50, 60, 106, 110, 113, 117, 119, 120, 121, 131, 142, 155, 158, 160, 170, 172, 173, 178, 180 and 185. RPS 40-1, RPS 40-2, RPS 62-3, RPS 61-1, RPS 69-2, RPS 72-2, RPS 75-1, RPS 102-1, RPS 107-1, RPS 113-1, RPS 120-1, RPS 147-1, CO-2 and Keharpur	Murthy and Harinarayana (1989)
RPS 62-3, RPS 41, RPS 75-2 and RPS 123	Singh *et al.* (1990)
GPUK 3, GPUK 4, KMV 20, RPS 136-1 and JK 41 RPS 136-1, GPUK 3, PSC 1, KK 1, IGBKK 3 and KMV 20	Singh *et al.* (1997)

High plant density may increase the effectiveness of natural enemies in reducing the pest population. In kodo millet, low plant density contributed towards decrease in larval population and incidence of shoot fly (Singh, 1984; Murthy and Harinarayana, 1989). While, higher plant density increases the number of shoot flies, egg laid and plant attacked. Thus, the density of plant has a significant influence on oviposition by shoot fly (Davis and Reddy, 1982). A seed rate of 10 kg/ha has been found optimum for higher grain yield with low incidence of shoot fly.

The use of inorganic fertilizers to enhance the plant nutrition often influence the longevity and fecundity of insects (Murthy and Harinarayana, 1989). The experimental results indicated that nitrogenous fertilizers increases while phosphatic fertilizers reduces the shoot fly infestation (Singh *et al.*, 1993). The application of 20 N + 20 P_2O_5 kg/ha has been found optimum for better crop growth, grain yield with low infection of shoot fly.

Elimination of weeds reduces the shoot fly infestation in kodo millet. One hand weeding, 20-25 days after sowing checks the attack of this pest and resulted in economically higher yield (Singh *et al.*, 1993).

The intercropping of kodo millet with pulses and oilseeds has found beneficial in reducing the infestation, development and movement of shoot fly.

Chemical control: The soil application of BHC 10% (20 kg/ha), Methyl parathion 2% (20 kg/ha) or Quinolphos 5% (2 kg a.i./ha) dust were most

effective and economically cheaper in controlling the shoot fly infestation in kodo millet if applies on 10 days older seedlings in clear weather (Singh *et al.*, 1993). Raghuwanshi and Rawat (1985) reported that application of Carbofuron (1 kg a.i./ha) and Quinolphos 5 g (2 kg a.i./ha) as soil treatment was effective against shoot fly in kodo millet. Spraying of Endosulphon (0.07%) or monocrotophos (0.04%) or phosphomidon (0.03%) after 10 days of germination have found effective in controlling shoot fly incidence in kodo millet.

CHAPTER 6

Seed Production

The development of new variety has value only when seeds in genetically pure form become available to the growers. This involves the identification, release, registration and notification of varieties under Indian Seed Act 1966 and their maintenance through systematic seed production programmes. The availability of quality seed is the most vital and essential input for sustainable production. The yield gaps exists between minikits/ FLDs and average yield of state/country in kodo millet can be bridge-up by making available quality seed of improved varieties in sufficient quantities to replace the local cultivars. Thus, the selection of appropriate variety and its quality seeds are the principal factors for increasing and stabilizing the production. About 27 improved varieties of kodo millet have been released/notified till date, but organized seed production programme of these varieties is rather very limited. The benefits of current research will not thus reach to the farmers unless large scale seed multiplication programmes are organized. The seed producing agencies need to be directed with specific targeted mandate to produce the quality seed of this minor cereal. Presently, most of the farmers are bound to use the seed of traditional cultivars and consequently have not been able to exploit the higher production potential of recently released varieties.

SEED MULTIPLICATION CHAIN

Seeds of notified varieties are multiplied in four tier system (Fig. 9) by the involvement of ICAR Institute/state agricultural universities, seed certification agencies and national/state seed corporation.

Nucleus seed

This is the cent-per cent genetically pure seed with physical purity and produced by the original breeder/institute/SAUs from basic nucleus seed stock. A pedigree certificate is issued by the producing breeder.

Breeder's seed

The progeny of nucleus seed multiplied in large area as per indent of DOAC (Department of Agriculture and Co-operation), Ministry of Agriculture, Government of India under supervision of plant breeder/

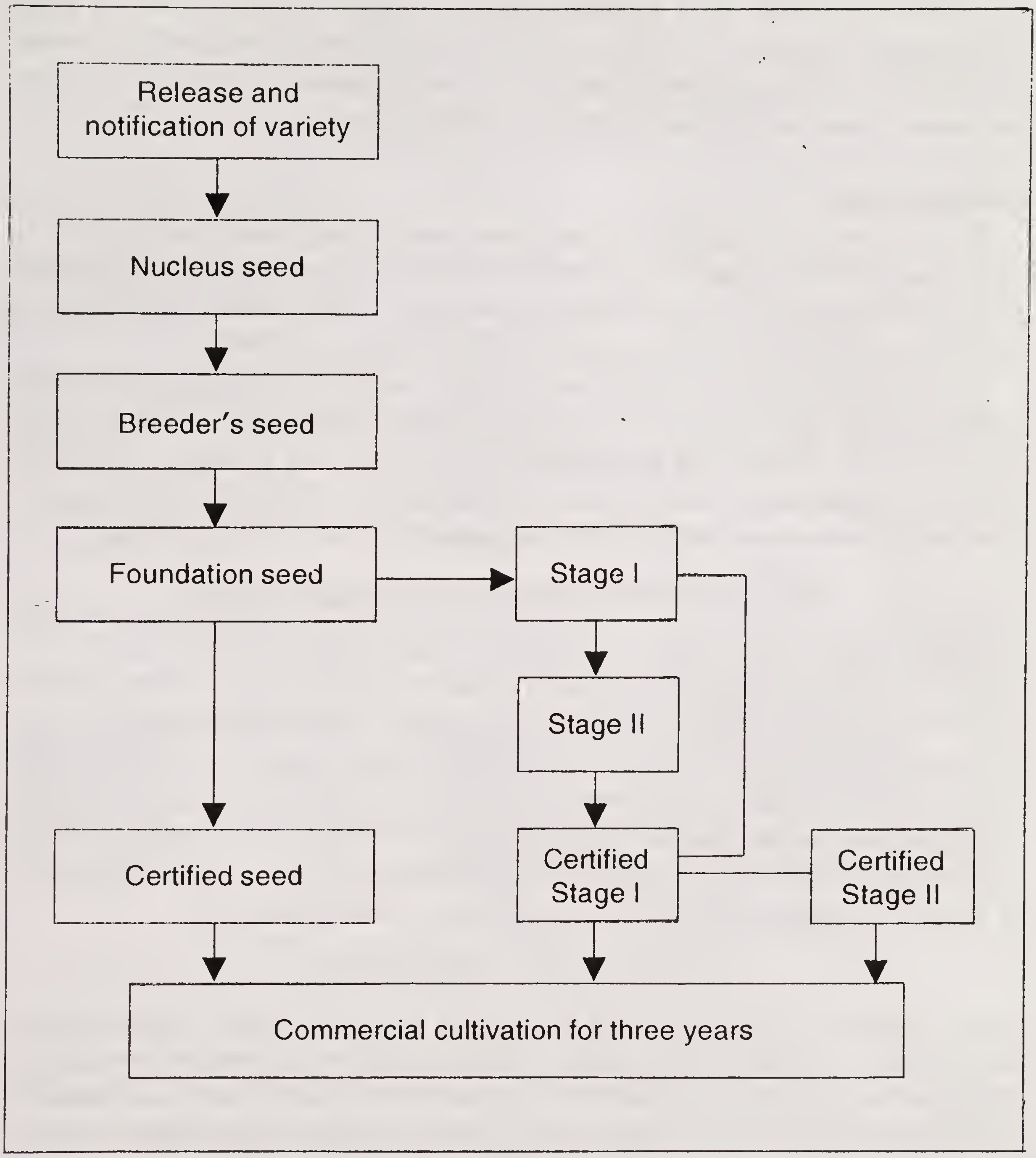

Fig. 9. Seed multiplication chain in kodo millet

institute/SAUs and monitored by a committee consisting of the representatives of state seed certification agency, national/state seed corporations, ICAR nominee and concerned breeder. This is also cent-per cent physical and genetic pure seed for production of foundation seed. A golden yellow colour certificate is issued for this category of seed by producing breeder.

Foundation seed

The progeny of breeder seed produced by recognized seed producing

agencies in public and private sectors under supervision of seed certification agencies in such a way that its quality is maintained according to prescribed field and seed standards. A white colour certificate is issued for foundation seed by seed certification agencies.

Certified seed

The progeny of foundation seed produced by registered seed growers under supervision of seed certification agencies to maintain the seed quality as per minimum seed certification standards. A blue colour certificate is issued by seed certification agency for this category of seed.

The foundation and certified seeds can be multiplied at stage I and stage II, but the reproduction can not exceed three generations after breeder seed. In kodo millet, the production of nucleus and breeder seed have slightly increased in recent years, but its further multiplication chain is hampered in most of the kodo millet growing states of the country.

IMPORTANT DIAGNOSTIC CHARACTERS

The diagnostic characters of varieties in kodo millet can be earmarked from beginning of vegetative growth to the maturity, because classification of varieties based on morphological characters is essential for identification and seed certification. The use of distinct qualitative and quantitative traits with high heritability as mentioned by the developing breeder is equally important in the production of genetically pure seed. Thus, the important diagnostic characters for identification of kodo millet varieties are given in Table 25 along with pattern of variation in each character.

MAINTENANCE BREEDING

The improved varieties of self pollinated crop like kodo millet should theoretically be completely homogeneous, but in practice, the stage of complete homogeneity is seldom reached and a considerable amount of variation may still occur during seed production cycle specially in newly released varieties. The purification of such variety during maintenance/ production of nucleus/breeder's seed may therefore be necessary.

Nucleus seed production

Basic seed is required to be grown in sufficient area for selection of true to the type plants as per descriptor of the variety. The progeny of selected plant is grown in single row keeping more plant to plant and row to row distance than normal recommendations and field standards are maintained. The individual plant progenies should be visited and observed by the concern breeder right from germination to different growth stages.

Table 25. Important diagnostic characters

Characters	Stage	Variation
Growth habit	Vegetative	Erect/ decumbent/ prostrate
Degree of culm branching	Flowering	Low (3)/ medium (5)/ high (7)
Sheath pigmentation	Flowering	Absent / present
Sheath base pigmentation	Flowering	Absent / present
Juncture pigmentation	Flowering	Absent / present
Internodes pigmentation	Flowering	Absent / present
Lamina pigmentation	Flowering	Absent / present
Flag leaf	2nd primary axis node	Absent/ rudimentary/ well developed
Ear exertion	Dough	Complete/ partial
Ear appearance	Dough	Open/ semi-compact/ intermediate
Spikelet arrangement in rachis	Maturity	Regular rows in upper half and irregular in lower half of inflorescence/2 to 3/ 2 to 4 irregular rows
Plant height	Maturity	Dwarf/ medium/ tall
Basal tiller	Maturity	Low/ medium/ high
Days to maturity	Maturity	Early/ medium/ late
Grain shape	Maturity	Orbicular/ ellipsoidal/ oval
Grain colour	Maturity	Grey brown/ brown/ dark brown

Source: Ramakrishna *et al.* (2002)

Any plant progeny deviating from characters of original variety or showing disease incidence should be removed from the field. The entire single plant progeny should be removed on occurrence of off type or diseased rather than roughing single plant. True to the type single plant progenies should be harvested and threshed separately by avoiding the physical mixtures. The seeds of true to the type progenies left after rejection both at pre- and post-harvest stages should be bulked to designate as nucleus seed.

Breeder's seed production

The nucleus seed along with diagnostic features of the variety are the prerequisites for breeders's seed production. The quantity of nucleus seed depends on the indent received through proforma BSP I to concerned breeder/institute/SAUs. The nucleus seed is sown with less seed rate in lines on well prepared and fertile lands, which fulfill the field standards.

Immediately after germination, producing breeder submits BSP II to ICAR and DOAC, Ministry of Agriculture, Government of India. The breeder must visit the plot at regular interval to rough out off type plants. The monitoring of breeder seed field is to be arranged at flowering and maturity by the breeder. The report of monitoring team containing information about genetic purity is to be submitted in BSP III. Care should be taken during harvesting, threshing and processing to avoid any type of mixtures and damage of seed. The final figure of graded quantity of produced breeder seed is to be submitted through the proforma BSP IV. Further, seed is tested for seed standards in recognized seed testing laboratories and a yellow coloured certificate is attached with bag containing required information, seal and signature of the concerned breeder. The quantity of seed lifted or not lifted as per allocation is to be submitted through proforma BSP V.

Production of foundation and certified seed

The foundation and certified seeds are produced under supervision of seed certification agencies at the farms of seed corporations and government. However, certified seed can be produced at farmer's field also. The producer of foundation and certified seeds have to be applied for production programme in prescribed proforma 1-2 months prior to sowing time, to the seed certification agency for allotment of the programme and its further processing. After selection of producer and their field for seed production programme, the producer has to submit the prescribed fee and to purchase the breeder seed for foundation seed production programme or foundation seed for certified seed production programme. The seed inspectors from seed certification agency visit the field of seed production 2 to 3 times in cropping season to verify the source of seed, variety, genetic purity and prescribed field standards as mentioned in Table 26. In first visit, the seed inspector can advise the grower to

Table 26. Field standards for seed certification in kodo millet

Field standards	Foundation seed	Certified seed
Minimum field inspection (Number)	3	3
Minimum isolation distance (meter)	3	3
Maximum off type (%)	0.05	0.10
Maximum objectionable weeds (%)	-	-
Maximum different crop plants (%)	-	-
Maximum objectionable diseases (%)	-	-

Source: Tunwar and Singh (1988)

Table 27. Seed standards for seed certification in kodo millet

Seed standards	Foundation seed	Certified seed
Minimum physical purity (%)	97	97
Maximum inert matter (%)	3	3
Maximum other distinguishing varieties (Number/kg)	-	-
Maximum other crop seed (Number/kg)	10	20
Maximum total weed seed (Number/kg)	10	20
Maximum objectionable weeds (Number/kg)	-	-
Maximum objectionable diseases (Percentage by number)	-	-
Minimum germination (%)	75	75
Maximum moisture (%)		
Ordinary container	12	12
Vapour proof container	8	8

Source: Tunwar and Singh (1988)

improve the production programme if required, whereas in second and third inspection, he rejects or selects the programme on the basis of genetic purity and field standards. At maturity, the grower harvests, threshes and dries the seed properly by avoiding mechanical mixtures and bags the same to transfer the seed at registered seed processing plant. The seed is processed under observation of seed inspector. The under size seed obtained after grading is returned back to the grower. The quality seed is stored as a lot with a code number in seed processing plant. The seed inspector submits a sample from this lot to recognized seed testing laboratory for analyzing the minimum seed standards (Table 27) after payment of prescribed fee. The seed lot is passed or rejected based on seed testing. After seed testing report, the seed inspector issued the tags for seed category.

STRATEGIES FOR INCREASING SEED PRODUCTION

Present level of seed production in kodo millet from national/state seed corporation and seed production farms is not well organized and mostly failed to cater the seed demands. It therefore becomes essential to accelerate the seed production programme in this crop. Seed Villages, *Beej Swablamban* and seed exchange programmes need to be implemented in the areas of kodo millet cultivation to meet the seed requirements. In these programmes, seed villages/farmers are identified in selected districts for multiplying the seeds of improved varieties according to certified seed

production programmes. The number of selected villages/farmers will depend on the seed requirement. It is also presumed that about 10% area will be saturated with the improved seed after 4th year operation of this programme. The remaining areas will then be covered by natural spread of improved varieties. Since, kodo millet is the staple food of economically weaker section of the society, it is suggested that subsidy should be given for the purchase of improved seeds, fertilizers, pesticides and credit for raising healthy seed crop at reasonable rate. Further, the farmers should be given a guarantee for the purchase of produced seed at a remunerative price.

Beside, these programmes, the private agencies, NGOs and voluntary agencies need to be encourage for seed production programme in kodo millet. It will help in maintaining the quality seed of improved varieties and to make available to farmers at their doorstep at reasonable rates. The government can also support these organizations in the production and supply of kodo millet varieties.

CHAPTER 7

Processing and Utilization

Kodo millet is mostly consumed by tribal and economically poor people after hulling of the grain. However, the dehulied grains are also occasionally consumed by higher section of the society as a small rice. The coarse texture, characteristic flavour and less luster after cooking along with non-availability of processed products similar to rice are the primary reason for their consumption by traditional consumers.

MILLING

The milling process of kodo millet grains includes the dehusking and debranning along with the polishing. The traditional method of dehusking using earthen mortar with wooden pastel (chakara) and debranning by hand operated wooden pastel (moosal) still persists. (Fig.10 and 11). Pushpamma (1989) reported that both dry and wet abrasive methods are used for dehulling of kodo grains. These methods takes time and demand high energy because of the presence of multilayered husk on the grains of kodo millet. The bran layer covers starchy endosperm similar to rice. Hence, its milling can be performed by rice mills (Malleshi and Hadimani, 1993). Considering these facts, the rice milling machine (Kisan rice polisher) was tested on 4 varieties of kodo millet in Madhya Pradesh. The milling was performed at different machine speeds, viz. 255, 335, 530 and 700 rpm and at different moisture contents of the grain, viz. 10.6, 12.0, 13.6, 14.0 and 15.0%. Results indicated that 530 rpm and 12.0% moisture content were most suitable for kodo millet (Singh, 1994a). The variation in milling efficiency and husk content with number of passes at 530 rpm and 12.0% moisture content of the grain are shown in Fig.12 and Fig. 13, respectively. Kodo millet variety GPLM 352 was found best among the tested varieties for milling performance. Later on, Singh (1994a) tested two pairs of combination of dehusking cum polishing material using CIAE general purpose grain rice polisher and Kisan rice polisher having lower energy and upper rubber roll for milling of kodo millet along with other small millets. Kodo millet has given the good result in this combination with milling efficiency of 99.5% at 12% moisture content of the grain (Fig 14). Sharma and Madhyan (1992) tested milling performance of some kodo varieties at Jabalpur (Madhya Pradesh). They found highest percentage

Fig. 10. Traditional method of dehusking
Source: All India Co-ordinated Research Project on Small Millets, Rewa (Madhya Pradesh)

Fig. 11. Traditional method of debranning
Source: All India Co-ordinated Research Project on Small Millets, Rewa (Madhya Pradesh)

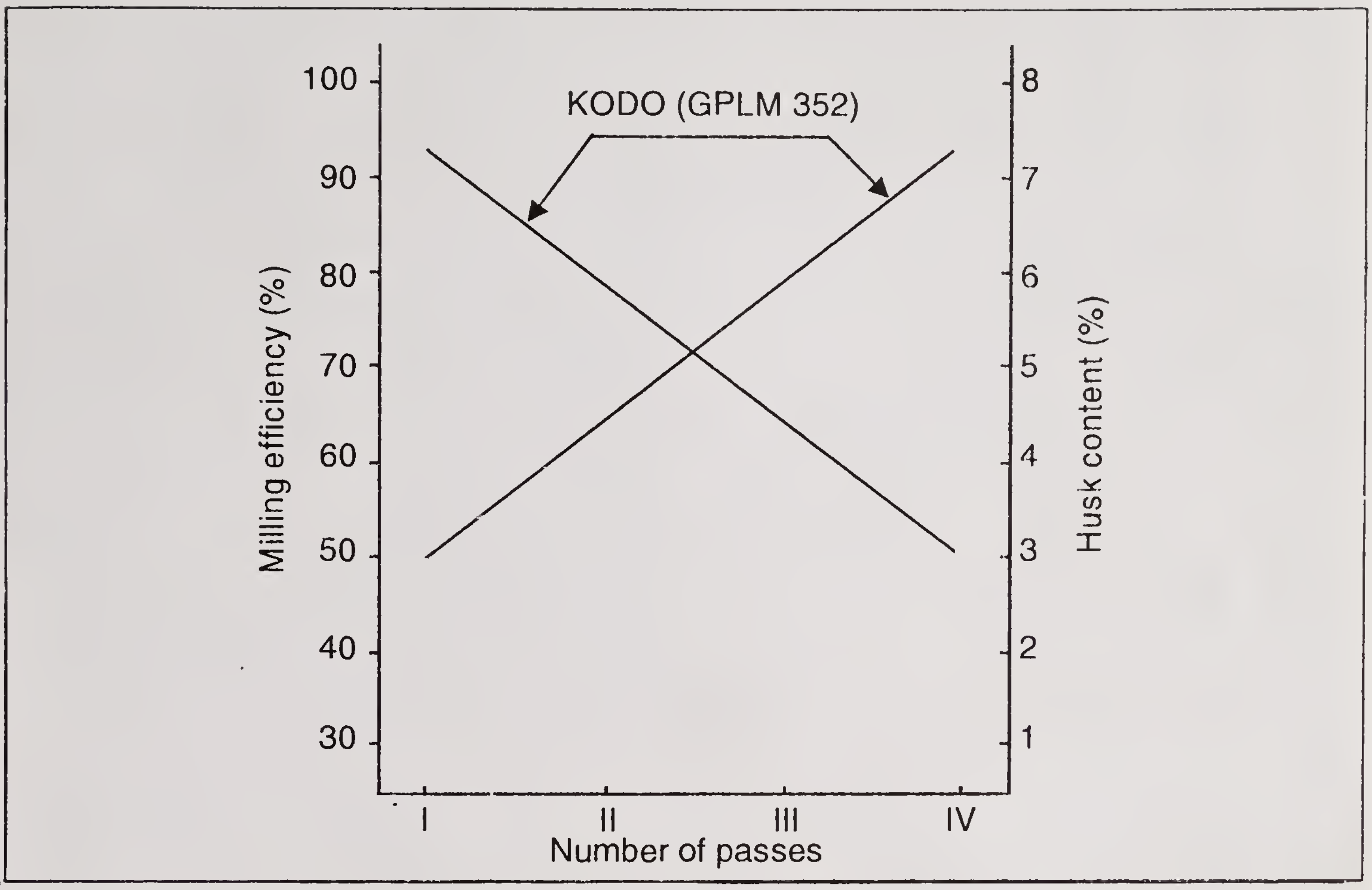

Fig. 12. Variation in milling efficiency and husk content with number of passes at 530 rpm for kodo millet

Source: Singh (1994a)

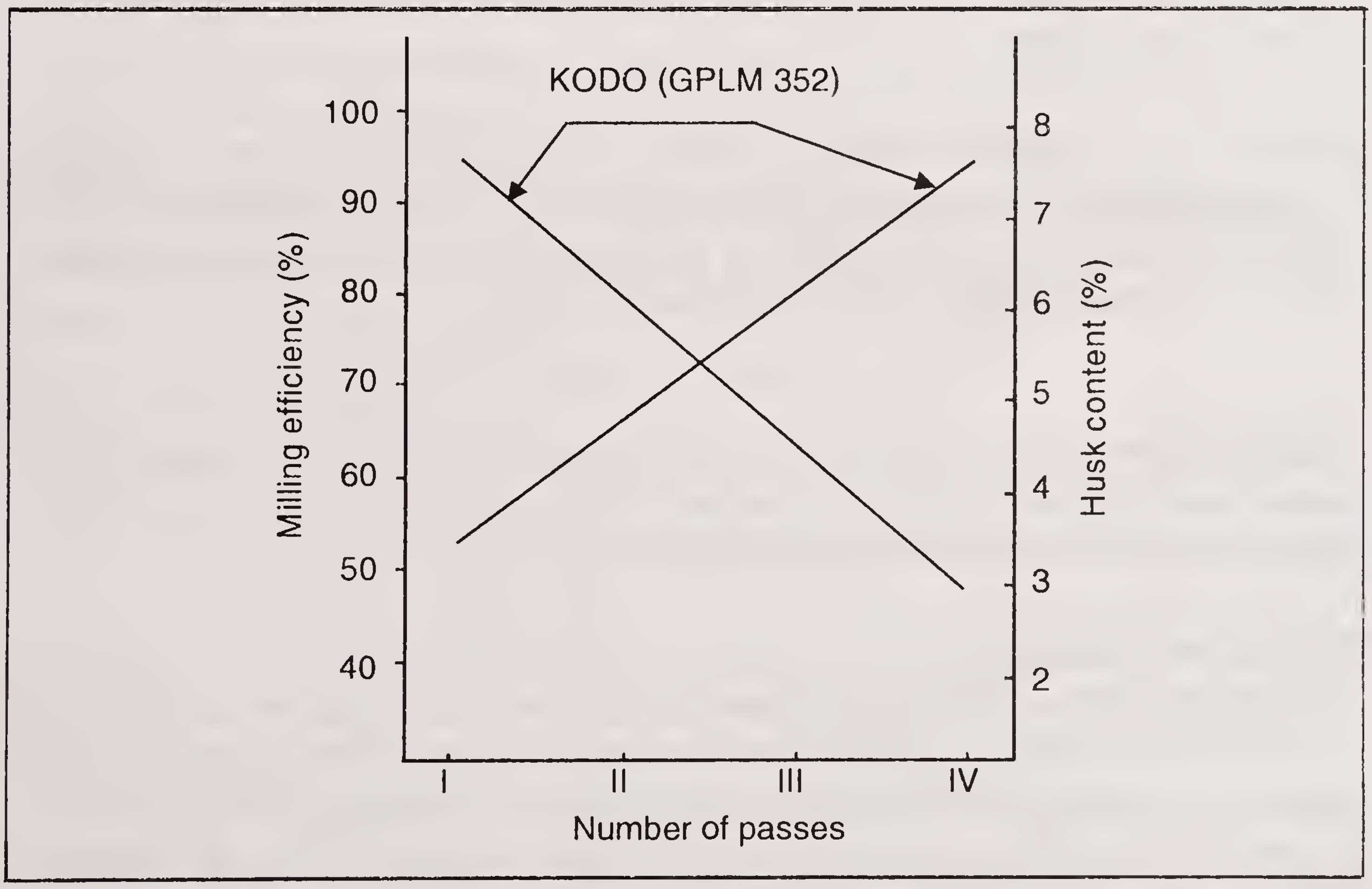

Fig. 13. Variation in milling efficiency and husk content with number of passes at 12% moisture content for kodo millet

Source: Singh (1994a)

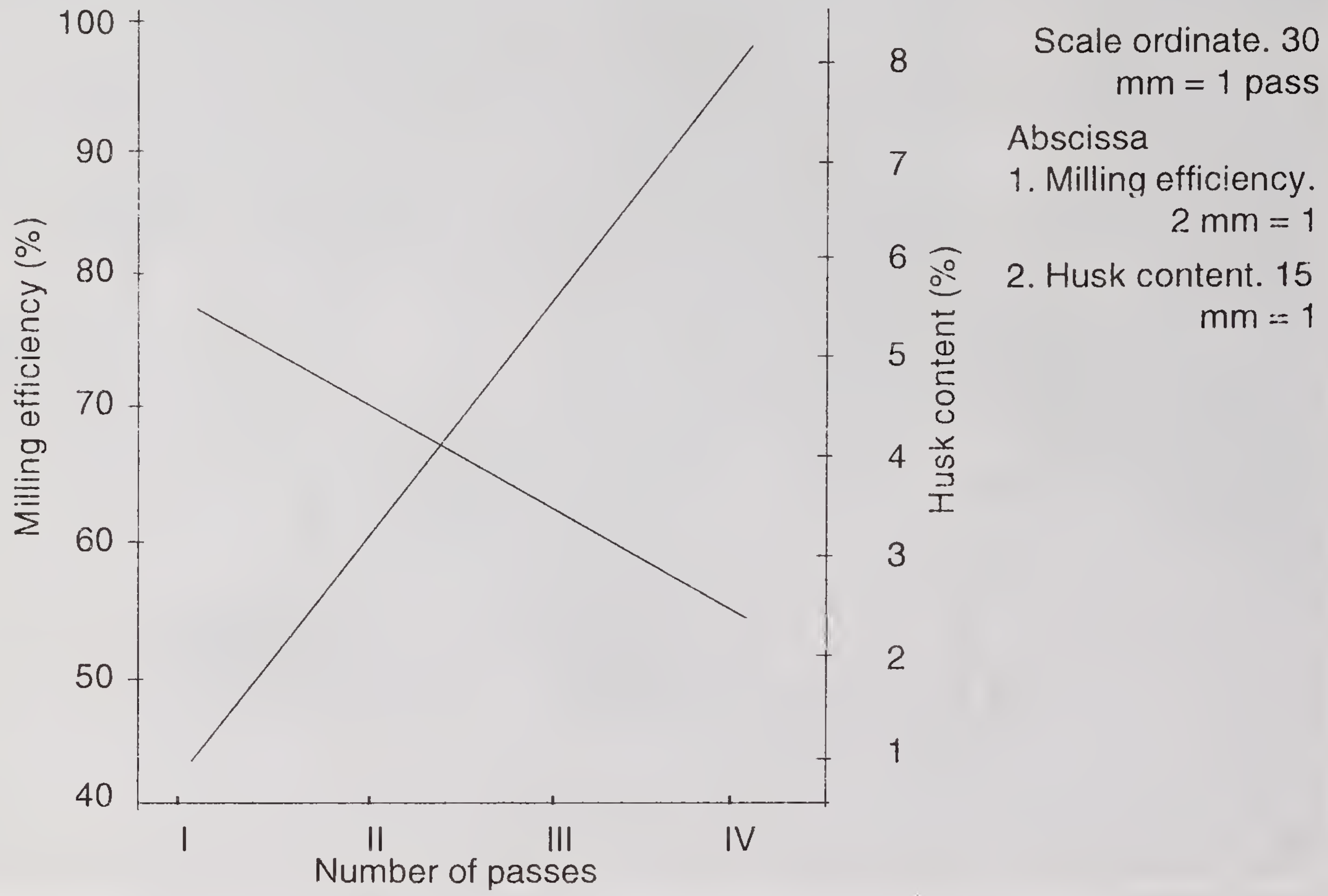

Fig. 14. Variation in milling efficiency and husk content with number of passes at 12% moisture content for kodo millet using CIAE general purpose mill and *kisan* rice polisher
Source: Singh (1994a)

of dehusk grain (60.84%) with least broakens (12.13%) in kodo variety JK 76. The coefficient of dehulling and milling efficiency was highest in RPS 123 (95.11%) and JK 76 (80.25%). It indicated that dehulling and milling efficiency varied with genotypes in kodo millet.

GRAIN QUALITY

Kodo millet provide a better and cheapest nutrition as compared to other food grains to their consumers. The physical and nutritional properties of the grains are described below.

Physical properties

The grains of kodo millet are round to oval in shape, light to dark brown in colour. It contains 18.64% husk on an average which varied from genotype to genotype. The debranned grains are white to dull white in colour and resembles to rice (Fig. 15). Bran contains 25.2% fats (Seiber, 1987). Sharma and Madhyan (1992) reported the variation among physical properties of grain in kodo millet. The slenderness ratio ranged from 1.01 to 1.05%. The sphericity was between 0.88 and 0.90. The range of variation

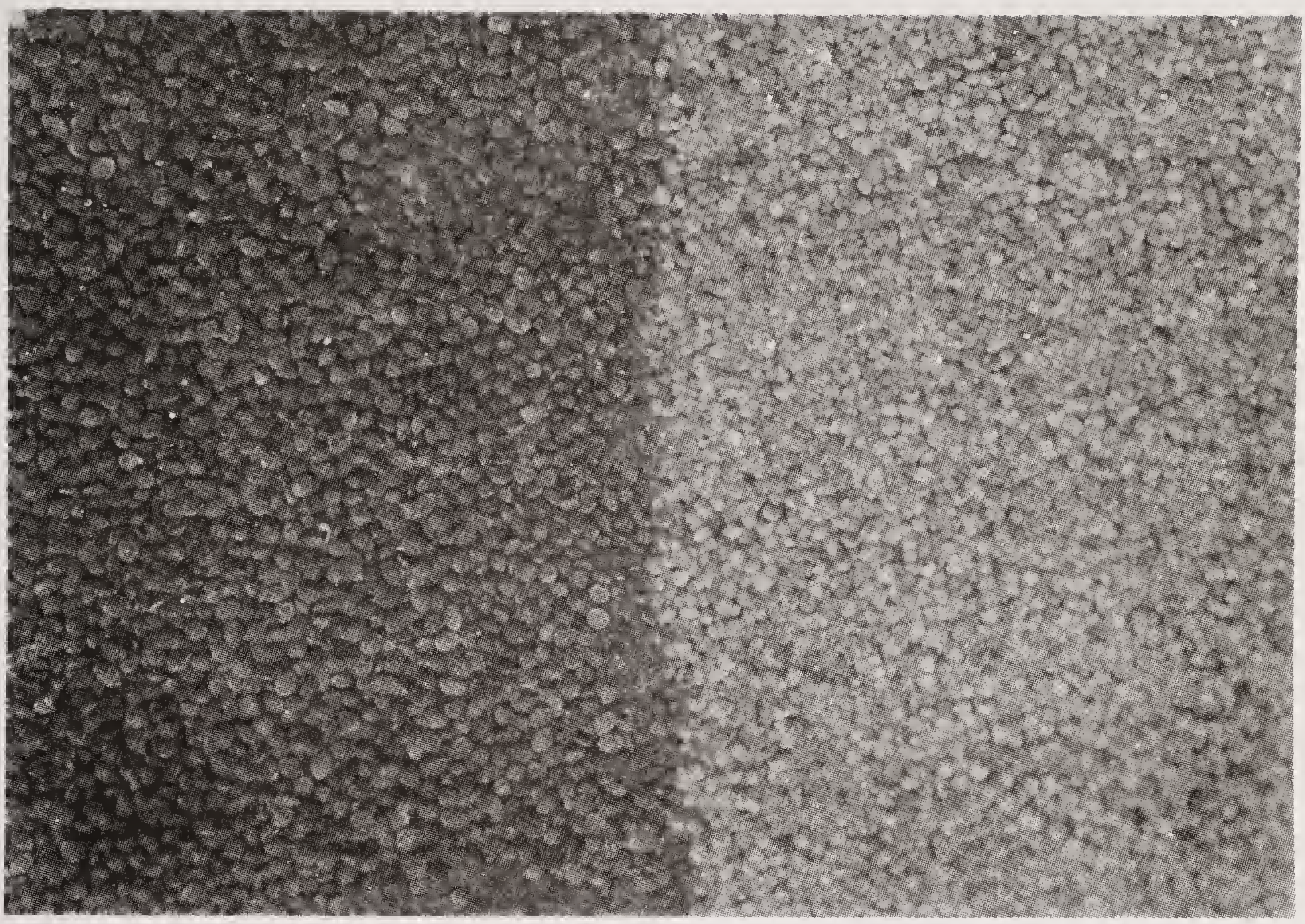

Fig. 15. Grain and debranned grain (rice) of kodo millet
Source: All India Co-ordinated Research Project on Small Millets, Rewa (Madhya Pradesh)

was 52.60–63.00 kg/hectolitre weight, 1.08–1.22 for specific gravity and 0.44–0.51 red for angle of repose. Kodo millet variety Jk 41 possessed highest slenderness ratio, hectolitre weight and crushing resistance. While, RPS 123 recorded higher water uptake in comparison to rest of the tested genotypes. Similar variation in physical characteristics of grains has also been reported by Madhyan *et al.* (1987) and Verma (1989).

Nutritional properties

The milled grain of kodo millet contains 11.7% water, 72.2% starch, 0.7% fibre, 7.2% alluminoides, 2.1% oil and 5.3% ash. The protein content of the grains ranged from 7.38 to 9.48%. Koutu (1989) recorded variation in protein, starch, Cu, Zn, Fe, Mn content of the grains as influenced by genotypes and locations. The average estimate of these nutrient parameters over locations was 5.55% for protein, 69.12% for carbohydrate, 11.29 ppm for Cu, 14.20 ppm for Zn, 8.72 ppm for Fe and 52.20 ppm for Mn.

Comparison of nutritional composition of kodo millet and other cereals revealed that kodo millet contains higher estimate of protein, fat, crude fibre and ash as compared to finger millet, rice and wheat except wheat protein. Among vitamins, the grains of kodo millet are rich in riboflavin

Table 28. Nutrient composition of kodo millet and other cereals (per 100 g edible portion and 12% moisture)

Crops	Protein (g)	Fat (g)	Ash (g)	Crude fiber (g)	Carbo-hydrate	Thiamine (mg)	Ribo-flavin (mg)	Niacin (mg)
Kodo millet	9.8	3.6	3.3	5.2	66.6	0.15	0.09	2.0
Little millet	9.7	5.2	5.4	7.6	60.9	0.30	0.09	3.2
Barnyard millet	11.0	3.9	4.3	13.6	55.0	0.33	0.10	4.2
Foxtail millet	11.2	4.0	3.3	6.7	63.2	0.59	0.11	3.2
Finger millet	7.7	1.5	2.6	3.6	72.6	0.48	0.19	3.2
Proso millet	12.5	3.5	3.1	5.2	63.8	0.41	0.28	4.5
Rice	7.9	2.7	1.3	1.0	76.0	0.41	0.04	4.3
Wheat	11.6	2.0	1.6	2.0	71.0	0.41	0.10	5.2

Source: FAO (1995)

as compared to rice and similar with wheat (Table 28). The essential amino acid composition of kodo grains indicated that it is rich in lysine and enylalanine amino acid. The grains also contains good amount of threonine and valine (Table 29). The kodo protein is deficient in tryptophane. The nutritional value can be improved by supplementation with legume protein, which is the major food habit in the country. The Protein efficiency ration (PER) of kodo millet becomes 0.92 to 1.90 when supplemented with chickpea and amaranthus leaves (FAO, 1995). The total chemical score of kodo grain is higher than little millet and barnyard millet and is equal to sorghum (Table 29). The mineral composition of kodo grain indicates that the grain is rich in Ca as compared to sorghum, little millet, barnyard

Table 29. Essential amino acid composition and chemical score of kodo millet and other cereals (mg/g)

Crops	Iso-leucine	Leusine	Lysine	Methio-nine	Enyla-lanine	Threo-nine	Trypto-phane	Valine	Chemical score
Kodo millet	188	419	188	94	375	194	38	238	35
Finger millet	275	594	181	194	325	263	191	413	52
Foxtail millet	475	1044	138	175	419	194	61	431	41
Proso millet	405	762	189	160	307	147	49	407	56
Little millet	416	679	114	142	297	212	35	379	33
Barnyard millet	288	725	106	133	362	231	63	388	31
Sorghum	245	832	126	87	306	189	63	313	37

Source: FAO (1995)

Table 30. Mineral composition of kodo millet and other cereals (mg%)

Crops	P	Mg	Ca	Fe	Zn	Cu	Mn	Cr
Kodo millet	215	166	31	3.6	1.5	5.80	2.90	0.080
Finger millet	320	137	398	3.9	2.3	0.47	5.49	0.028
Foxtail millet	422	81	38	5.3	2.9	1.60	0.85	0.070
Proso millet	281	117	23	4.0	2.4	5.80	1.20	0.040
Little millet	251	133	12	13.9	3.5	1.60	1.03	0.240
Barnyard millet	340	82	21	9.2	2.6	1.30	1.33	0.140
Sorghum	352	171	13	4.2	2.5	0.44	1.15	0.017

Source: FAO (1995)

millet and proso millet. Magnesium (Mg) is equivalent to sorghum and higher than rest of the small millets. The Cu is much higher in kodo millet as compared to rest of the coarse cereals except proso millet. Similarly, Mn is also higher than other cereals except finger millet. The Cr content of the grain is also superior than most of the coarse cereals (Table 30). It is thus clear that grains of kodo millet is very rich in minerals. Hence, it can be best for preparation of baby foods.

Fodder quality

Kodo millet is used as a fodder in dry areas. In developed countries, *Paspalum* is grown mainly for fodder or pasture production. The nutritional studies on forage quality of kodo millet are very limited, but the possibilities exists for use of crop in livestock feeding. The chemical composition of fodder as reported by Sen and Ray (1971) indicated that fresh early vegetative crop possessed high estimates of crude protein as

Table 31. Chemical composition in fodder of kodo millet (Per cent on dry basis)

Type of forage	Crude protein	Ether extract	Crude fiber	Nitrogen free extract
Fresh early vegetative	11.4	1.4	28.8	41.1
Fresh dough stage	5.7	1.5	31.6	49.1
Straw	3.5	1.5	34.3	48.4

Source: Sen and Ray (1971)

compared to proso millet, foxtail millet and finger millet. The other fodder qualities of the crop are described in Table 31. Tribal cultivators utilize the green fodder in checking the dysentery in domestic cattles.

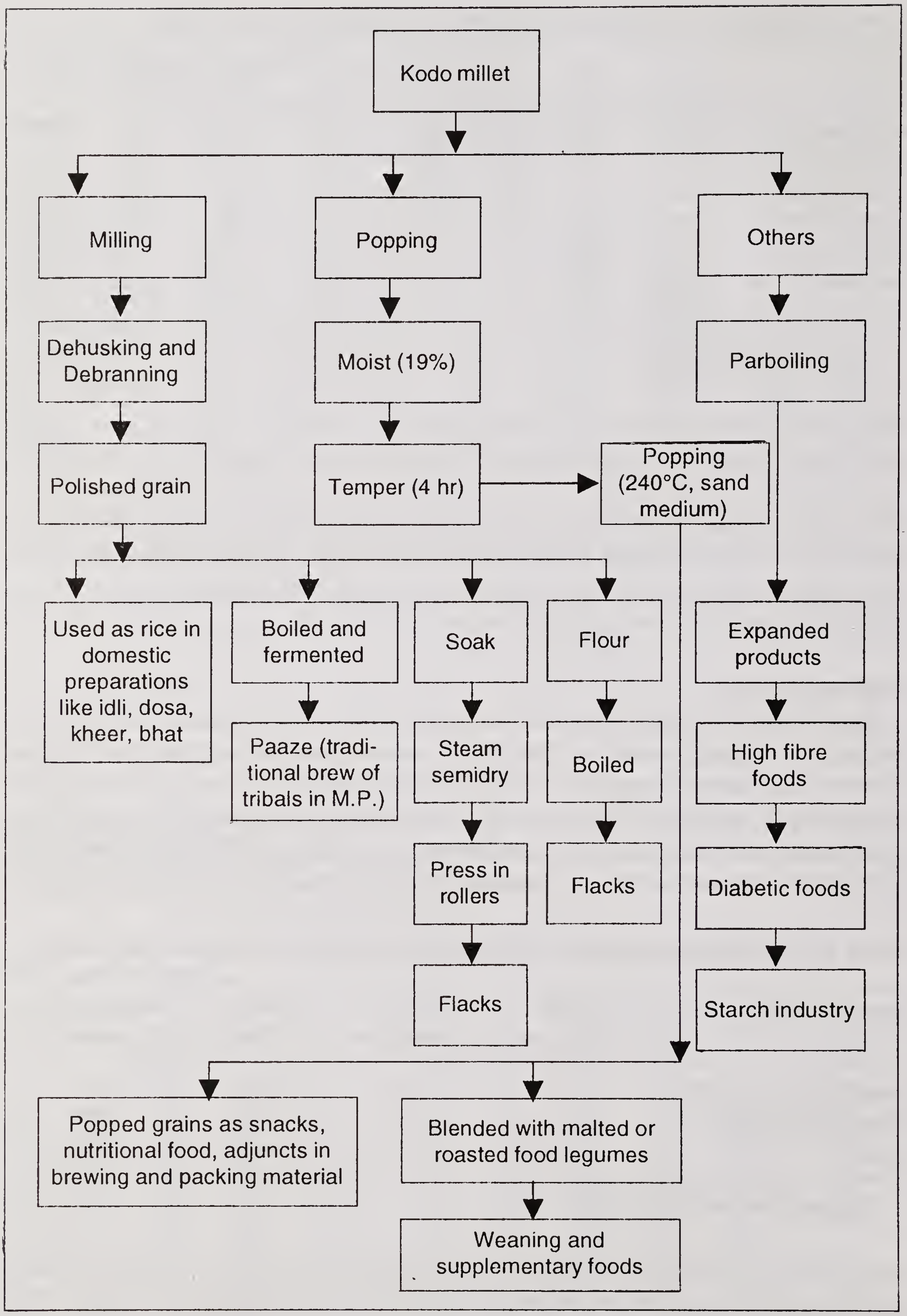

Fig. 16. Processing of kodo millet for food and industry

Food preparations

Kodo millet is used as food in the situations where other food grains can not be produced or purchased in economic rate. It is the main source of protein and minerals in the daily diets of tribal and weaker sections, living in remote rural areas. The grain is usually cooked as rice after milling and debranning (Fig 16). It is a good substitute of rice for diabetic patients. The dehusked and debranned polished grains can be used in domestic preparations like *idly, dosa, khir* etc. The tribal of Madhya Pradesh used kodo rice in preparation of *paaze*, which is cooked and fermented kodo rice. The beer with acceptable characters can be prepared by using the kodo millet as cheaper adjunct with barley (Roy, 2000). Kodo rice can be used in preparation of flacks by soaking the grains in water and steamed, semidried and subsequently pressed by rollers. The flour of kodo grains is also used in preparation of chips.

Popping of kodo millet grains is a common practice in their areas of production. The husked grains are moisten at 19%, tempered for 4 hr and then popped in sand medium at 240°C (Malleshi and Hadimani, 1993). The popped grains are used as snacks, breakfast food and packing aids. The popped grains are also blend with roasted food legumes and are used as supplementary foods. The industrial utilization of kodo grains are not thoroughly explored but being a rich source of protein, vitamins and minerals, it can be used in preparation of health food, bakery products, bird feed, extraction of starch and starch derivatives. Medicinally kodo plant is styptic, used in inflammation, diseases of liver, ulcer, dysentery and heat the body in human and cattle (Blatter *et al.* 1975).

Kodo plant is also a good source of fodder for cattle. In rural areas of Madhya Pradesh, the stover is used in construction of earthen houses, earthen bins, pots and local mattresses. The straw of kodo millet is also used as a suitable substrate for cultivation of mushroom (*Pleurotus* sp.) in tribal belts of Madhya Pradesh (Rai and Sharma, 1995).

CHAPTER 8

Socio-Economic Analysis

The produce of kodo millet is mostly utilized by its growers. In the years of surplus production, the farmers are bound to sell their produce to *sahukars* in local market in low rates. The crop has been included in special food production campaign by Government of India recently, but there is lack of organized procurement system till date in this crop. Being a coarse cereal, kodo millet is considered traditionally as no remunerative crop, but the recent studies indicated that substantial profit can be obtained by adoption of available improved technology in this crop.

Ahmad and Yadava (1996) evaluated the productivity and economics of small millets under agro-ecological conditions of Madhya Pradesh. They concluded that kodo millet have potential for higher grain yield as compared to rest of the crops. Average grain yield potential of kodo millet was 2.85 tonnes/ha, while it was lowest in little millet (9.72 tonnes/ha). With this productivity, the farmers can get a net profit of Rs 3,707 per hectare. The income per rupee invest was also higher in kodo millet with maximum return in recently released improved varieties like GPUK 3, RPS 136-1 and KMV 20.

The vast gaps in realizing productivity of kodo millet at experimental area and farmers field compelled Ahmad and Yadava (1997) for crop cutting experiment on improved and traditional practices of cultivation at farmers field. The study carried out in district Sidhi of Madhya Pradesh revealed that broadcasting method of sowing is predominant in kodo millet. The grain yield recorded in line sowing was 1.1 tonnes/ha as compared to 0.95 tonnes/ha in broadcasting method. The adoption of this single component of production technology resulted in an additional net return of Rs 426/hectare with income equivalent ratio of 1.28. It further indicated that potential exists in developed technology on this crop to make the crop remunerative under assured marketing and procurement system. It can be enhanced by searching the alternative uses of this crop.

BARRIERS IN TRANSFER OF TECHNOLOGY

The following barriers have been identified in transfer of technology from the experience gained in recent years:

1. The socio-economic conditions of kodo millet growers are poor. The

resource constraints thus remain always with growers. Hence, crop is cultivated without adequate inputs and result in low yield.

2. Rigidity of tribal farmers to their ancestral package and poor extension due to illiteracy.
3. Being a coarse cereal, the negligible attention is given by the extension agencies in highlighting the role and importance of improved technology.
4. Timely unavailability of quality seed and inputs in remote areas where kodo millet are actually cultivated.
5. Dearth of remunerative market for the produce and non-organized procurement system.

STRATEGIES FOR ENHANCING THE PRODUCTION

The vast untapped potential exists in technology presently available in kodo millet. There is need to explore it through various extension efforts. The following measures are suggested for enhancing the productivity of this crop:

1. Popularization of improved varieties and production technologies through full extension support.
2. By fixing the productivity target in advance and to increase the area under HYVs along with time bound comprehensive seed production programme.
3. Replacement of low yielding land races by improved varieties through seed exchange programme or providing seed of improved varieties free of cost.
4. Social and economic plan to supply the inputs directly to farmers in remote areas or through NGOs working for welfare of tribal.
5. Kodo millet is included recently in special food production campaign, but the special attention deserves for its proper execution.
6. The demand of this crop can be enhanced by including the kodo millet in public food distribution system. Kodo millet may be a better compulsory health food particularly in tribal schools, hostels and allied.
7. Commercial exploitation of alternative uses in form of health food, flakes, snacks, popped grains, bakery food and bird feed.
8. Training for better awareness of developed technologies and alternative uses in both men and women in the areas of kodo millet cultivation.
9. Providing adequate price support and marketing facilities under organized procurement and utilization system.

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